Oil and Gas Assesement of the Yukon Delta and Togiak National Wildlife Refuges

by
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see pg 5 for pages of Economic interest

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EXECUTIVE SUMMARY

The oil and gas potential for the Togiak and Yukon Delta National Wildlife Refuges (NWRs) has been classified into three categories of low, moderate and no Potential for the occurrence of oil and gas. The moderate potential is for gas only.

The no potential is in the mountainous area of the Togiak and eastern Yukon Delta NWRs. The Togiak-Goodnews, Kilbuck and Nyac Terranes are predominantly of volcanic, and volcaniclastic and metamorphic rocks that have been severely deformed, and have been determined to have no potential for the generation and the accumulation of oil and gas.

The Yukon Delta NWR is classified into low and moderate potential. There are two areas of low potential: (1) The area between the Kuskokwim River and the Kilbuck Mountains and north near Aniak. This area is centered within a high-magnetic lineament and may be underlain by concealed volcanic and/or metamorphic terranes; (2) The western Yukon Delta area (lower Yukon Basin). The mid-Cretaceous sedimentary rocks that are exposed within this area are severely deformed graywacke and siltstone that have low reported permeability and porosity value. The organic content of these rocks is woody-coaly, gas prone type kerogen with a minimal total organic content generally less than 0.5 percent.

The moderate potential area (Bethel Basin) is for gas only. The Cretaceous rocks penetrated by the Napatuk Creek Well No. 1. are characteristically overmature for liquid hydrocarbon, but are thermally mature for gas generation; gas-prone type kerogen was reported for the entire well. Insignificant shows of coal gas were reported from the well. Also the area is underlain by thick Cretaceous sedimentary rocks that seem to have apparent porosity in which a gas reservoir could exist.

Introduction

The following report is an oil and gas assessment of the Yukon Delta and Togiak National Wildlife Refuges (NWRs). It is part of a continuing cooperative agreement between the U.S. Fish and Wildlife Service (FWS) and the Bureau of Land Management (BLM) established under a Memorandum of Understanding (MOU) in 1986. This MOU established mutual responsibility for assessing the oil and gas potential of NWR lands of Alaska, as mandated by Section 1008 of the Alaska National Interest Lands Conservation Act (ANILCA).

ANILCA requires the Secretary of the Interior to initiate an oil and gas leasing program on the Federal lands of Alaska. ANILCA exempts ". . . those units of the National Wildlife Refuge system, where the Secretary determines, after having considered the national interest in producing oil and gas from such lands, the exploration for and development of oil and gas would be incompatable with the purpose for which such unit was established." Section 1008 mandates:

> "In such areas as the Secretary deems favorable for the discovery of oil or gas, he shall conduct a study, or studies, or collect and analyze information obtained by permittees authorized to conduct studies under this section, of the oil and gas potential of such lands and those environmental characteristics and wildlife resources which would be affected by the exploration for and development of such oil and gas."

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This report will further identify those lands within and around the Yukon Delta and Togiak NWRs which are most favorable for the discovery and development of oil and gas, in order that FWS can determine which lands within the refuges will be permitted for oil and gas leasing.

where

Location and Physiography

The Yukon Delta and Togiak NWRs, located in southwestern Aláska, encompass over 26 million acres and 4.7 million acres of land, respectively (plate 1). Together, these refuges contain over 30 million acres of land. Their boundaries run along both Bristol Bay and Kuskokwim Bay (Togiak NWR) to Norton Sound, taking in Yukon-Kuskokwim lands, including Nelson and Nunivak Islands (Yukon-Delta NWR).

Togiak NWR

The Togiak NWR lies within the northern Bristol Bay region. Its western boundary extends from the Kanektok River, along Kuskokwim Bay to Cape Newenham on the Bering Sea, rounds Cape Newenham to Cape Pierce, then east along Bristol Bay to Nushagak Bay, approximately 65 miles (120 km) from the town of Naknek on the Alaska Peninsula. The area's eastern boundary is bordered by the Wood River-Tikchik State Park, approximately 400 miles (640 km) west of Anchorage, and its northern boundary is adjacent to the Yukon Delta NWR.

The refuge exhibits a variety of landforms and topographical features, consisting of mountainous uplands, low smooth hills, and coastal lowlands, including beaches, lagoons, estuaries, sea cliffs, and numerous bays. The mountainous upland regions are a group of rugged steep-walled mountains that extend across the refuge's interior from the Ahklun Mountains, on the west, to the Wood River Mountains in the east. These mountains have undergone intense glaciation; they have serrated ridges and sharp pinnacle-like peaks which range from 2,000 to 5,000 feet (600 m to 1,538 m) in elevation, and rise abruptly from the surrounding lowlands. The mountains are separated by broad, U-shaped valleys; many of which contain glacial lakes with reported depths of as much as 900 feet (278 m). The highest peak is Mt. Waskey, 5,045 feet (1,538 m), in the northeastern corner of the refuge; it has a few small glaciers. The southwestern portion of the refuge has lower, smoother hills and smaller mountains, with rounded summits that range from 1,000 to 2,500 feet in elevation (300 m to 700 m) (Wahrhaftig, 1966; Mertie, 1938). The broad and flat Togiak Valley separates the Ahklun Mountains from the Wood River Mountains.

The Nushagak Peninsula is part of the Nushagak-Bristol Bay lowlands; it consists of morainal and outwash deposits that rise from sea level to 500 feet (150 m) in elevation, near the outer margin of the Wood River Mountains. The peninsula contains the largest wetland area within the refuge. It has innumerable lakes and sloughs and low gradient streams that drain the coastal lowland and marsh. Other lowland areas are adjacent to Jacksmith, Chagvan, Osviuk, and Nanvuk Bays.

The refuge is drained primarily by four major river systems that debouche into Kuskokwim and Bristol bays. The rivers are generally shallow and swift and tend to follow the structural grain of the mountains. The Kanektok and Goodnews rivers drain the west and southwest portion of the refuge, originating in the Ahklun Mountains and emptying into Kuskokwim and Goodnews Bays. The Togiak River drains the central part of the refuge and is the largest drainage system within the refuge, draining both the Ahklun and Wood River Mountains before emptying into Togiak Bay on Bristol Bay. The Igushik River drains the southeastern portion of the Wood River Mountains. The Igushik River originates at Amank Lake and meanders through the Nushagak lowland. Many shorter rivers, streams, and tributaries drain the coastal area of the refuge; these include slow moving, low gradient streams that drain the coastal lowlands and marshes and short, fast moving, high gradient streams that drain the coastal slope.

Nearly all the refuge lands are within the Ahklun Mountains physiographic province with the exception of the coastal lowlands along Kuskokwim Bay and the Nushagak Peninsula; these areas belong to the Yukon-Kuskokwim lowlands and Nushagak-Bristol Bay lowlands, respectively (Wahrhaftig, 1966).

Yukon-Delta NWR

The Yukon Delta NWR is the largest of all of Alaska's 16 National Wildlife Refuge systems. The refuge extends from Norton Sound and the Nulato Hills, in the north, to Kuskokwim Bay, in the south, and from the Kilbuck Mountains in the east to the coastal margin of the Bering Sea (plate 1), and includes Nunivak and Nelson Islands. The dominant physiographic feature of the refuge is the triangular coalescent delta of the Yukon and Kuskokwim rivers. These rivers have created a vast coastal lowland, extending 250 miles (400 km) from Norton Sound in the north to Kuskokwim Bay in the south, and from the coastal margin of the Bering Sea 200 miles (320 km), to the Kilbuck Mountains in the east. For the most part, the coastal lowland of the Yukon-Kuskokwim Delta is a low-lying, marshy plain dotted with innumerable lakes and ponds and criss-crossed by extremely low gradient streams. Many of the streams are former distributary channels of the Yukon and Kuskokwim rivers. The general elevation of the plain ranges from sea level to 300 feet (0-92 m), with a few low-lying hills in the western margin of the plain. The Ingakslugwat Hills, north of Baird Inlet (plate 1), rise in elevation from 300 to 600 feet (92-185 m). The Ingakslugwat Hills are composed of basaltic lava flows that are topped by cinder cones with broad shallow craters. The Askinuk and Kusilvak Mountains are the most prominent topographical features and rise abruptly out of the plain. The Askinuk Mountains are located north of Hooper Bay, between Scammon and Kokechik Bays. They run approximately 40 miles from Cape Romanzof eastward to Kingokakthluk Lake and range from approximately 800 to 2,400 feet (250-740 m) in elevation. This is the only part of the plain that shows evidence of glaciation. The Kusilvak Mountains, located 40 miles southwest of St. Mary's in the Marshall and Kwiguk quadrangles, are 8 miles long (north to south) and 5 miles wide (east to west) (plate 1). They rise abruptly out of the plain to 2,300 feet (700 m) in elevation.

In contrast to the coastal lowlands, are the upland hills to the north (Nulato Hills) and the mountains to the southeast (Kilbuck Mountains). The southern extension of the Nulato Hills is located within the northern boundary of the refuge, between Mountain Village and Marshall along the Yukon River and north to St. Michael (plate 1). These hills are northeast trending, with smooth crested ridges that range from 1,000 to 3,000 feet (300-925 m) in elevation and are separated by stream valleys. The Kilbuck Mountains, located in the southeastern part of the refuge, are the southern extension of the Kuskokwim Mountains. These mountains trend northeastward and range in elevation between 2,000 and 3,500 feet (615-1,076 m), with round to flat top ridges (Wahrhaftig, 1966).

The refuge also encompasses Nelson and Nunivak Islands. Nelson Island is adjacent to the delta plain and is separated from it by the Ninglick River to the north, Baird Inlet on the northeast, and the Kolvinarak River on the east. The southern portion of the island has low-lying, gentle slopes that become more rugged to the north with peaks between 700 and 1,400 feet (276-430 m) in elevation. Nunivak Island lies approximately 20 miles (32 km) southwest of the delta and is of volcanic origin with several peaks 1,000 to 1,600 feet (300-492 m) in elevation.

The Yukon and Kuskokwim rivers are the major drainages of the refuge and the two largest rivers in Alaska. The Yukon River begins in British Columbia, Canada, and flows approximately 2,300 miles (3,700 km) to the Bering Sea. The river is presently building a delta in Norton Sound. Three major tributaries flow at right angles to the Yukon within the NWR. These are the Andreafski, Atchuelinguk, and Archuelinguk rivers. The Kuskokwim River is the second largest river in Alaska. It flows 680 miles (745 km) from its headwater in the Alaska Range southwest to the Bering Sea by way of Kuskokwim Bay. The mouth of the Kuskokwim River appears to be that of a drowned river mouth. Smaller rivers within the NWR are the Eek, Kwethluk, Kisaralik, Tuluksak, Aniak, Gweek, Johnson, and Kialik rivers, with the Eek, Kwethluk, Kisaralik, Tuluksak, and Aniak rivers originating in the Kilbuck Mountains.

PREVIOUS WORK

The earliest geological investigation of southwestern Alaska, including Bristol Bay and the Yukon-Kuskokwim Delta region, was done by W. H. Dall in 1870. He worked in the vicinity of St. Michael and the lower Yukon River. Russell followed in 1890 with his exploration of the Yukon River. Dawson (1894) reported observation of Nunivak and Nelson Islands on his Bering Sea cruise in 1891. In 1898, the first exploration by the U.S. Geological Survey (USGS) in southwestern Alaska was that of Spurr (1900), who traversed the the Kuskokwim River from its headwaters to its mouth. He then traversed east, passing north of the Goodnews Bay area, to the Togiak River, and along the coast to the Alaska Peninsula. The discovery of gold in the early 1900s in the Bristol Bay and Kuskokwim areas led to a geologic reconnaissance north of the Goodnews Bay area by Harrington (1921). He produced a 1:250,000 scale geologic and topographical map from this study. Following the discovery of gold, platinum was discovered south of the Goodnews Bay area. Mertie (1940) published a detailed topographic and geologic map of the area. Cady (1955) described the geology of the central Kuskokwim area. Hoare and Coonrad, 1946-1953, systematically mapped the regional geology of the northern Bristol Bay and lower Kuskokwim regions. This resulted in a published geologic map at 1:250,000 scale for the Bethel and Russian Mission quadrangles (1959a, b) and the Goodnews and Hagemeister Island quadrangles (1961a, b). In 1970, the area was reexamined as part of the Alaska Mineral Resource Appraisal Program (AMRAP). Subsequently, Hoare and Coonrad published a more refined geologic map which included parts of the adjoining quadrangles (Bethel, Taylor Mountain, Dillingham, and Nushagak Bay). This early mapping showed the area to be structurally complex with varied stratigraphies. Efforts to understand the complexity led to subdivision of the area into four tectono-stratigraphic terranes by Jones and others (1981) and later detailed mapping and terrane analysis by Box (1985a, b, c).

Interest in petroleum possibilities for the Yukon-Kuskokwim Delta region began in the early 1950s when Gryc and others (1951) and Miller and others (1959) suggested that the area might be a (possible) petroleum province. Between the mid-1950s and early 1960s, oil and gas activity expanded into the

14,910 Depth Minor Show

Bq30, 32, 33, 34 ... Appendix 3-9

the only reported description

11,618 to 11,635 some bleeding of gas from fractures or from mud drilling muds

area. Oil companies conducted geologic investigations within the delta area and carried out limited geophysical exploration in the Bethel area. This resulted in the drilling of one exploratory well in 1961; Napatuk Creek No. 1, southwest of the town of Bethel. It yielded unfavorable results and exploration and leasing activity rapidly declined. Much of the geological and geophysical information generated by oil companies is not publicly available.

Hoare and Condon conducted regional geologic investigations within the Yukon-Kuskokwim Delta area between 1960 and 1963 and published a series of 1:250,000 scale geologic maps with stratigraphic and structural interpretations for the Kwiguk and Black (1966), Hooper Bay (1968), Marshall and St. Michael (1971) quadrangles. Patton (1973) described the geology of the adjacent Yukon-Koyukuk province to the north.

Many other researchers contributed to the understanding of the geology of southwestern Alaska. They are listed in the bibliography.

LITHOLOGY AND STRATIGRAPHY

The lower Kuskokwim-northern Bristol Bay region, including the Togiak and the eastern Yukon-Delta NWRs, is a structurally complex area with rocks ranging from Precambrian to Quaternary in age. Early mapping by Hoare and Coonrad (1959a, 1961a, b, and 1978b), and later by Box (1985a, 1986), groups these rocks into several mappable units. Most of the rocks are of volcanic arc, trench-slope, oceanic and continential affinity. The mapped units are: Precambrian metamorphic complex and Paleozoic and Mesozoic rocks consisting of Devonian (Ordovician?) tuffaceous limestone; Permian limestone and volcanic rocks, including pillow basalt, mafic flows and volcaniclastics; Triassic volcanic-volcaniclastic rocks, and bedded cherts; Lower to Middle Jurassic volcanic and interbedded sedimentary rocks, ~~and~~ volcaniclastics; Middle to Upper Jurassic volcaniclastic and sedimentary rocks and a basaltic and andesitic volcanic complex; Early Cretaceous and/or Jurassic volcanic rocks, tuffaceous argillite and chert; Early Cretaceous (Valanginian and Hauterivian) conglomeratic graywacke and shale (graywacke of Buchia ridge); Middle Cretaceous (Albian to Conician) conglomerates, interbedded graywacke, siltstone and shale, of the non-marine and marine Kuskokwim group; Upper Cretaceous conglomerate, sandstone, shale, and carbonaceous mudstone of the non-marine Summit Island formation; and Quaternary basalt flow and surficial deposit, with intrusive rocks of Late Triassic gabbroitic and serpentinized ultramafic composition; Middle Jurassic ultramafic and mafic and Late Cretaceous (or) Early Tertiary granitic rocks (plate 2, table 1). The Paleozoic and Mesozoic rocks were previously mapped as the undivided Gemuk group by Hoare and Coonrad (1959a, b; 1961a, b, 1978).

The structural complexity and the variable exposures of the area pose difficulties in establishing correlations and/or other relationships between the various lithological units. In most cases, stratigraphic thicknesses are indeterminate with most of the rocks being highly deformed and faulted. While some areas have well defined stratigraphic sequences, other areas do not (depositional contacts are rare, most bedded rocks having faulted contact) or have significantly different and/or coeval stratigraphies. In most cases, they do not correlate to adjacent quadrangles, nor can they be very well explained by faulting or facies changes. This lithologic heterogeneity is rationalized by the concept of tectonostratigraphic terranes, the application of which results in the subdivision of the area into four such terranes: the Togiak, Goodnews, Kilbuck, and Nyac Terranes (plate 3). (Tectonostratigraphic terranes are defined as fault-bounded, geological provinces whose inherent stratigraphy and geologic history are significantly different from that of a nearby or adjacent terrane (Jones and others, 1981).) Box (1985a) subdivided the Togiak and the Goodnews Terranes and Decker and others (in prep, 1987) include the Tikchik Terrane of Jones and Silberling (1979) as a subterrane of the Goodnews Terrane (plate 3). The following description of the stratigraphy and lithological units are primarily summarized from Box (1985a, b).

Togiak Terrane (T)

The Togiak Terrane ranges from Late Triassic through Early Cretaceous in age and consists of thick assemblages of volcanic and volcaniclastic rocks, including pillow basalt tuff, breccias, conglomerates, graywacke, radiolarian chert, and argillite (Silberling and Jones, 1984). The Terrane has undergone low-grade metamorphism of prehnite-pumpellyite to lower greenschist facies (Box, 1985a). The Terrane is divided into two northeast trending subterranes, the Kulukak and Hagemeister.

Hagemeister Subterrane (THA)

The Hagemeister subterrane (THA) is composed of three stratigraphic sequences separated by angular unconformities (plates 3 and 4). The lowest sequence is an ophiolitic sequence (Newenham Ophiolite) with Upper Triassic radiolarian chert that grades up through a thick volcanic breccia into a Lower Jurassic shallow marine volcaniclastic, and is locally intruded by Middle Jurassic mafic and ultramafic plutons (the pluton is between the thrust contact of the Goodnews and Togiak Terranes). In other areas, a granitic pluton intrudes the lowest sequence. The second sequence consists of Middle and Upper Jurassic (Bajocian-Tithonian) marine to non-marine volcanic and volcaniclastic rocks with a near-base conglomerate of granitic clastic and tightly folded volcaniclastic turbidites; this sequence overlies the lowest sequence as an angular unconformity (Box, 1985a, b). The third sequence consists of Lower Cretaceous (Valanginian-Albian) volcanic and sedimentary rocks. This unit occurs locally in four widely spaced belts (Murphy, 1986; Box, 1985a; Hoare and Coonrad, 1983). The belts are, from southeast to northwest: (1) the Buchia Ridge Belt which consists of an upper and lower unit with the lower unit consisting of a thickly bedded marine graywacke, siltstone, and conglomerates, and the upper unit consisting of a finer shale and shaley siltstone with thin interbedded graywacke and calcarenite. The belt is highly deformed and sheared in places, although elsewhere homoclinal.

ind

It is estimated to be over 5,000 m thick. (2) The Ungalikthluk Belt, is an isolated synclinal outcrop, consists of limestone (bioclastic) and limey, pebbly conglomerates, of subrounded quartz and schist, overlain by a non-calcareous graywacke and pebbly conglomerate. (3) Mount Oratia Belt consists of an upper section of thicker bedded graywacke and shale, and a lower section with an assemblage of tuff, volcanogenic sedimentary rocks, and argillite. These rocks are intensely folded and sliced by many faults. (4) The Eek Mountain belt, a large anticline, consists of massive bedded graywacke, shaley argillite, and conglomerates flanked by older Mesozoic and Paleozoic rocks of the Nukluk subterrane. The beds in the lower part of the section are thick-bedded to massive with rhythmially interbedded sandstone and shale, the upper part of the section is conglomerate and well bedded sandstone and shale, and the rocks are structurally deformed. The Kuskokwim group of Middle Cretaceous overlies the Eek Mountain Belt and is separated by a regional unconformity. These four belts overlie both the Goodnews and Togiak Terranes and cannot be related to any one terrane or a single depositional basin; therefore, these belts are considered to be part of the terrane they overlie (lK of plate 2 and Klc, Klt of figure 1).

Kulukak Subterrane (TKU)

The Kulukak subterrane (plates 3, 4) consists predominantly of Jurassic volcaniclastic turbidites and two structurally informal units, the Nunavarchak Complex to the northwest and the Graywacke of Metervik Bay, to the southeast, that are juxtaposed across a southeastern dipping thrust fault (right hand fault) (figure 1) (Box, 1985a).

The Nunavarchak Complex consists of complexly deformed, tuffaceous sedimentary rocks with preserved primary sedimentary structure indicating turbidite deposition. The sedimentary rocks are primarily argillaceous in nature with a lesser amount of interbedded fine- to coarse-to- pebbly volcanogenic sandstone.

The graywacke of Metervik Bay, interpreted as a turbidite facies, consists of an inner basal channelized volcaniclastic conglomerate facies to an outer progradational submarine fan complex. Box (1985a) described the lithology as "overwhelmingly" volcanogenic with plutonic clast content increasing up section. The Campanian to Maestrichtian nonmarine Summit Island Formation unconformably overlies both the Hagemeister and Kulukak subterrane consisting of fine-to-coarse sandstone, conglomerate, and carbonaceous shales overlain by an unnamed Upper Cretaceous volcanic and volcaniclastic sequence.

The Kulukak subterrane rocks that crop out along the upper broader end of the Nushagak Peninsula may extend beneath the Quaternary deposits to underlie the Nushagak Peninsula (plate 3). The contoured magnetic data over the western margin of the Nushagak Peninsula shows a "subcircular" magnetic anomaly, which Griscom (1978) interpreted as a concealed granitic pluton beneath the Quaternary sediments. It can be correlated to a Cretaceous-age granitic pluton exposed west of Kulukak Bay near the upper northwest corner of the Nushagak Peninsula (figure 1).

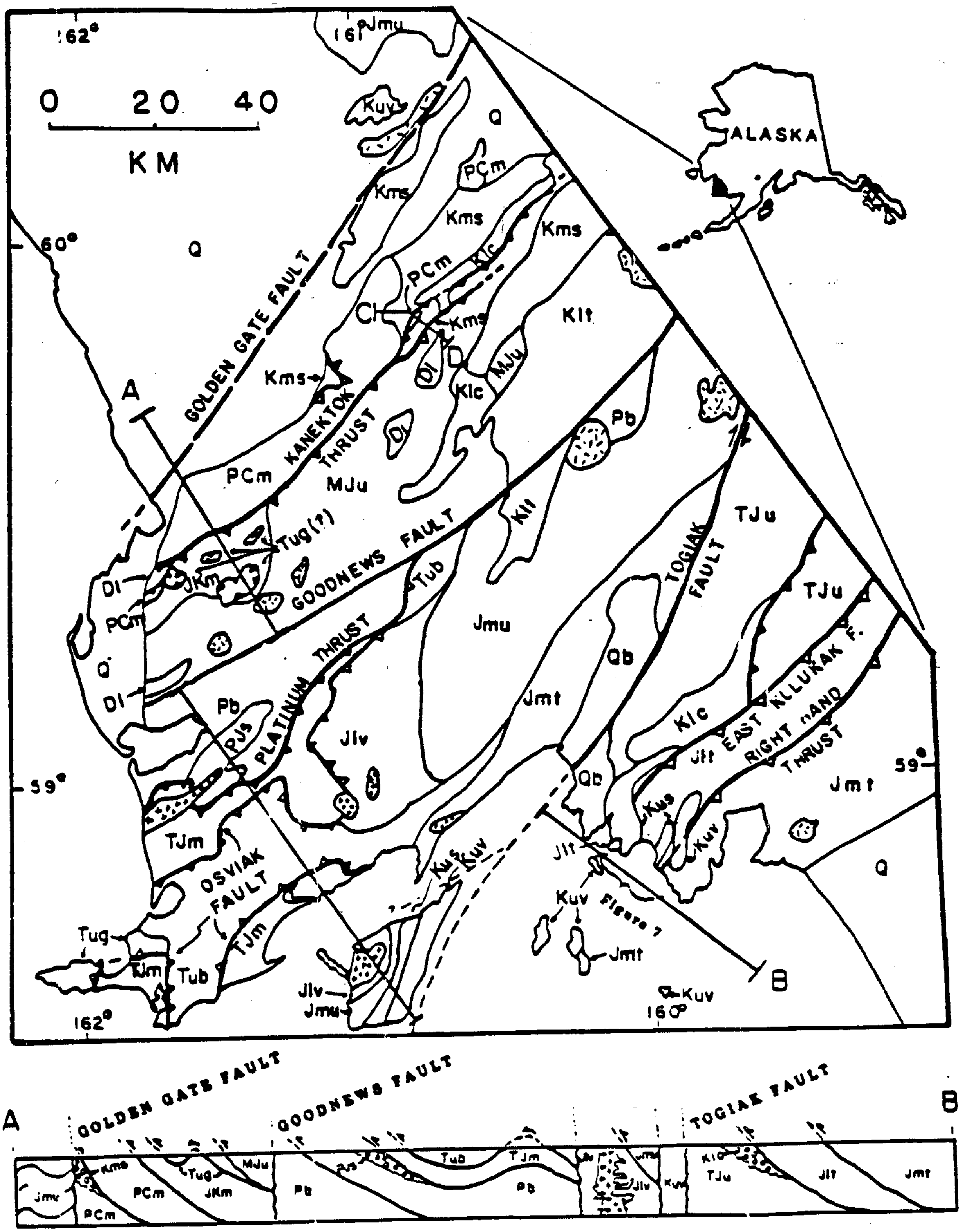


Figure 1.-Generalized Geologic Map and Cross-Section of the Togiak Area (from Box, 1985a).

GEOLOGIC MAP LEGEND

BEDDED ROCKS

Q - Quaternary unconsolidated sediments

Qb - Quaternary alkalic basalts

Kuv - Upper Cretaceous intermediate volcanic rocks

Kus - Upper Cretaceous nonmarine clastic strata

Kms - Mid Cretaceous deep to shallow marine clastic strata

Klc - Lower Cretaceous clastic strata

Klt - Lower Cretaceous tuffs and tuffaceous strata

Jmu - Middle and Upper Jurassic volcanic and volcaniclastic rocks

Jmt - Middle and Upper Jurassic volcaniclastic turbidites

Jlv - Lower Jurassic volcanic and volcaniclastic rocks

Jlt - Lower Jurassic (?) volcaniclastic turbidites, dismembered

TJu - Jurassic volcanic and volcaniclastic rocks, undifferentiated

Tub - Upper Triassic pillow basalts

Pb - Permian basalts and calcareous strata

MJu - Mississippian-Jurassic chert, basalt, tuff and limestone melange

Dl - Devonian (-Ordivician?) limestone

METAMORPHIC ROCKS

JKm - Jurassic/Early Cretaceous greenschists

TJm - Late Triassic-Early Jurassic greenschists

PCm - Precambrian amphibolite grade gneiss and schist

INTRUSIVE ROCKS

Late Cretaceous granites

Middle Jurassic ultramafic, mafic and intermediate plutons

Tug - Late Triassic gabbroic and serpentinized ultramafic rocks

SYMBOLS

high angle fault

low angle fault (teeth on upper plate)

C D location of cross section

Goodnews Terrane (GN)

The Goodnews Terrane consists of a complex assemblage of tuff, chert basalt, graywacke, limestone, gabbro, and ultramafic rock that underwent variable degrees of metamorphism. The rocks range in age from Devonian through Jurassic. The Terrane is subdivided into Cape Peirce, Platinum, and Nukluk subterranes. The Tikchik is included as a subterrane to the Goodnews Terrane based on its similarity in age, lithology, and structural deformation (Decker and others, in prep, 1987; plates 3 and 4).

Cape Peirce Subterrane (GCP)

The Cape Peirce subterrane consists of foliated (schistose) metamorphic rocks that crop out in the Cape Newenham and Cape Pierce areas. Three units are recognized and all are separated by low angle faults. The structurally highest unit consists of mafic schist; the middle unit of metaclastics; and the lowest of interbedded marble, slate, and mafic schist of probable Permian and Triassic ages. Each unit consists of a metamorphic mineral assemblage of the blueschist to greenschist facies.

Platinum Subterrane (GPT)

The Platinum Subterrane consists of mafic tuff with Permian fossils occurring in calcareous tuff interbedded with the mafic volcanic rock sequence and in limestone blocks between the Cape Newenham ophiolite complex along the boundary of the Cape Peirce subterrane. Mafic and ultramafic plutons of Middle Jurassic age intrude both the Platinum and the Cape Peirce Terranes. The rocks of this Terrane have been altered to prehnite-pumpellyite metamorphic facies.

Nukluk Subterrane (GNU)

The Nukluk subterrane ranges in age from Ordovician through Jurassic and is a structurally disrupted, melange-like unit containing blocks of various sizes and lithology which consists of radiolarian chert, partially recrystallized limestone interbedded with pillow basalt, tuff, breccia, and laminated green to black mudstones that are set in an argillaceous matrix (plate 4). The limestone blocks of Ordovician through Permian age are the most distinctive feature of the area, but only represent five percent of the total outcrop area and generally are structurally coherent, while the chert, tuff, and laminated mudstone are more structurally disrupted.

Metamorphic rocks of the Nukluk Terrane occur in the northwest margin, have blueschist to greenschist facies, and are structurally overlain by unfoliated mafic plutonic rocks. Serpentinite bands are scattered throughout the subterrane. The sedimentary rocks of the Eek Mountain belt overlie the Nukluk on its northeastern margin (Box, 1985a).

Tikchik Subterrane (GTC)

The Tikchik subterrane is a structurally complex assemblage of clastic rocks of radiolarian chert of Paleozoic and Mesozoic age, Permian limestone and clastic rocks, Permian or Triassic graywacke and pillow basalts, and Upper Triassic clastic and mafic volcanics. The subterrane is lithologically and structurally similar to the above Nukluk subterrane (Decker and others, in prep, 1987).

Kilbuck Terrane (Kl)

The Kilbuck Terrane consists of a completely recrystallized Precambrian metamorphic assemblage of continental affinity. This assemblage, defined by Hoare and Coonrad (1979), consists of quartz diorite, granodioritic gneiss, orthogneiss, garnetiferous amphibolite, marble and quartz mica schist. The rocks range from the upper amphibolite to lower greenschist facies. Locally, Cretaceous clastic rocks of the Kuskokwim Group unconformably overlie the Kilbuck Terrane.

Nyac Terrane (NY)

The Nyac Terrane consists of Middle to Upper Jurassic andesitic to basaltic volcanic and volcaniclastic rocks with interbedded graywacke, siltstone and conglomerate intruded by Cretaceous granite plutons. The western and northwestern boundary of the Terrane is not exposed, although magnetic data (Dempsey and others, 1957; Box, 1984b) shows the Nyac is truncated along a northeasterly trending magnetic lineament that follows the Kuskokwim River (plate 5, figures 2 and 3).

Portage Mountain Sequence (PMS)

The Portage Mountain Sequence, a terrane of unknown affinity (Decker and others, in prep, 1987), is exposed northwest of the Kuskokwim River near the village of Aniak (plate 1), in the east corner north of the Yukon Delta NWR. This terrane consists of volcanic and volcaniclastic rocks, green cherty tuff, graywacke, mudstone, calcareous conglomerate, and limestone. The sequence is highly deformed with a melange-like fabric. Permian fossils occur in the limestone within the sequence. This sequence was previously mapped as the undivided Gemuk Group by Hoare and Coonrad (1959b) (plate 3).

Kuskokwim Group

The Lower and Upper Cretaceous (Albian to Coniacian) clastic rocks of the Kuskokwim Group are deposited in the northeast-southwest trending Kuskokwim basin. The basin covers approximately 72,000 km^2 in southwestern Alaska (Bundtzen and Gilbert, 1983), extending from the Nowitna River,in the northeast (near its head water), to the Kanektok River, in the southwest, in the northern Goodnews quadrangle. The basin is cut by three major fault

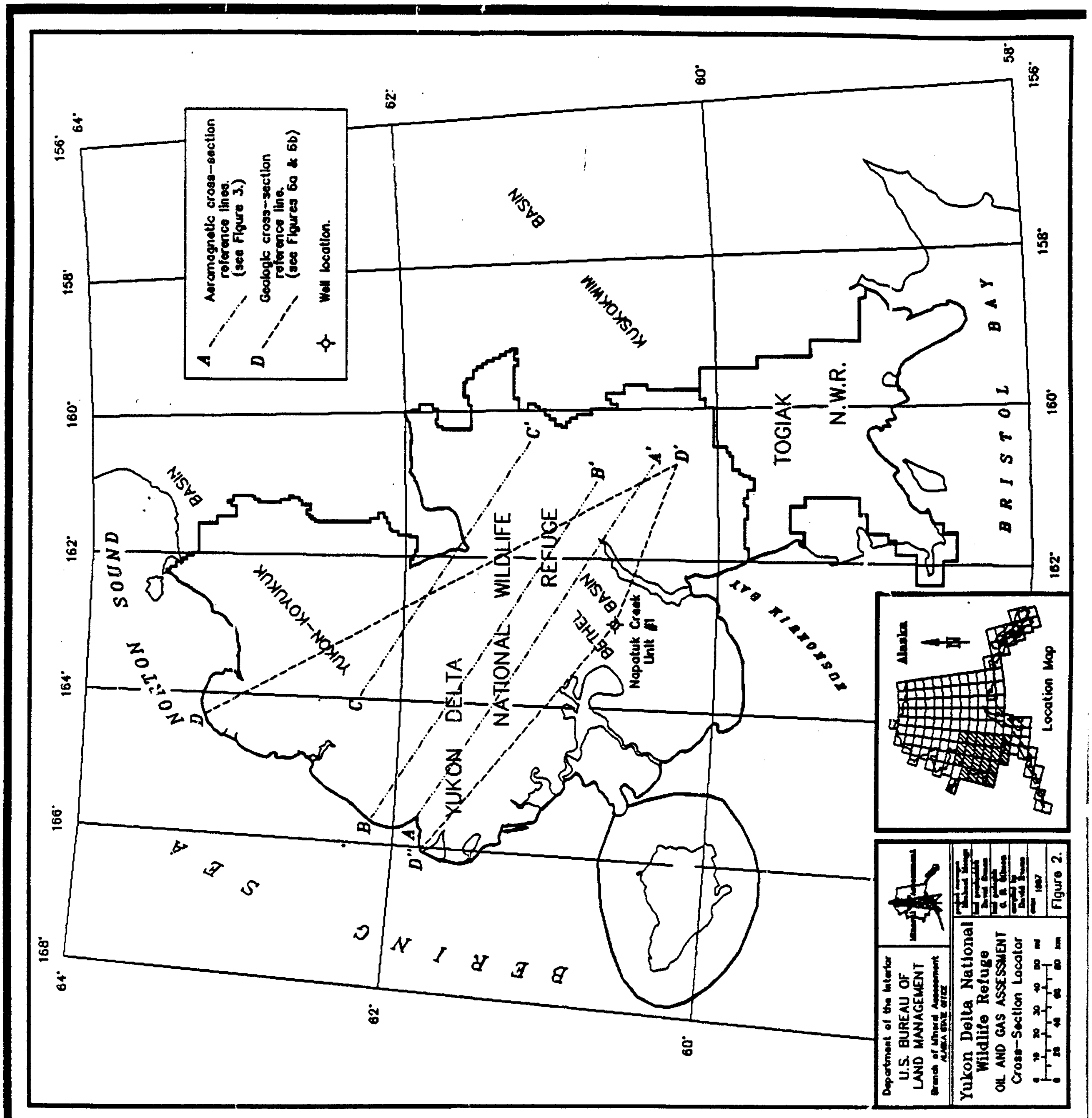


Figure 2.-Yukon Delta National Wildlife Refuge Oil and Gas Assessmert.

YUKON DELTA N. W. R.

Selected Aeromagnetic Profiles and Associated Surface Expression

= Flight Line (plotted on Basemap)

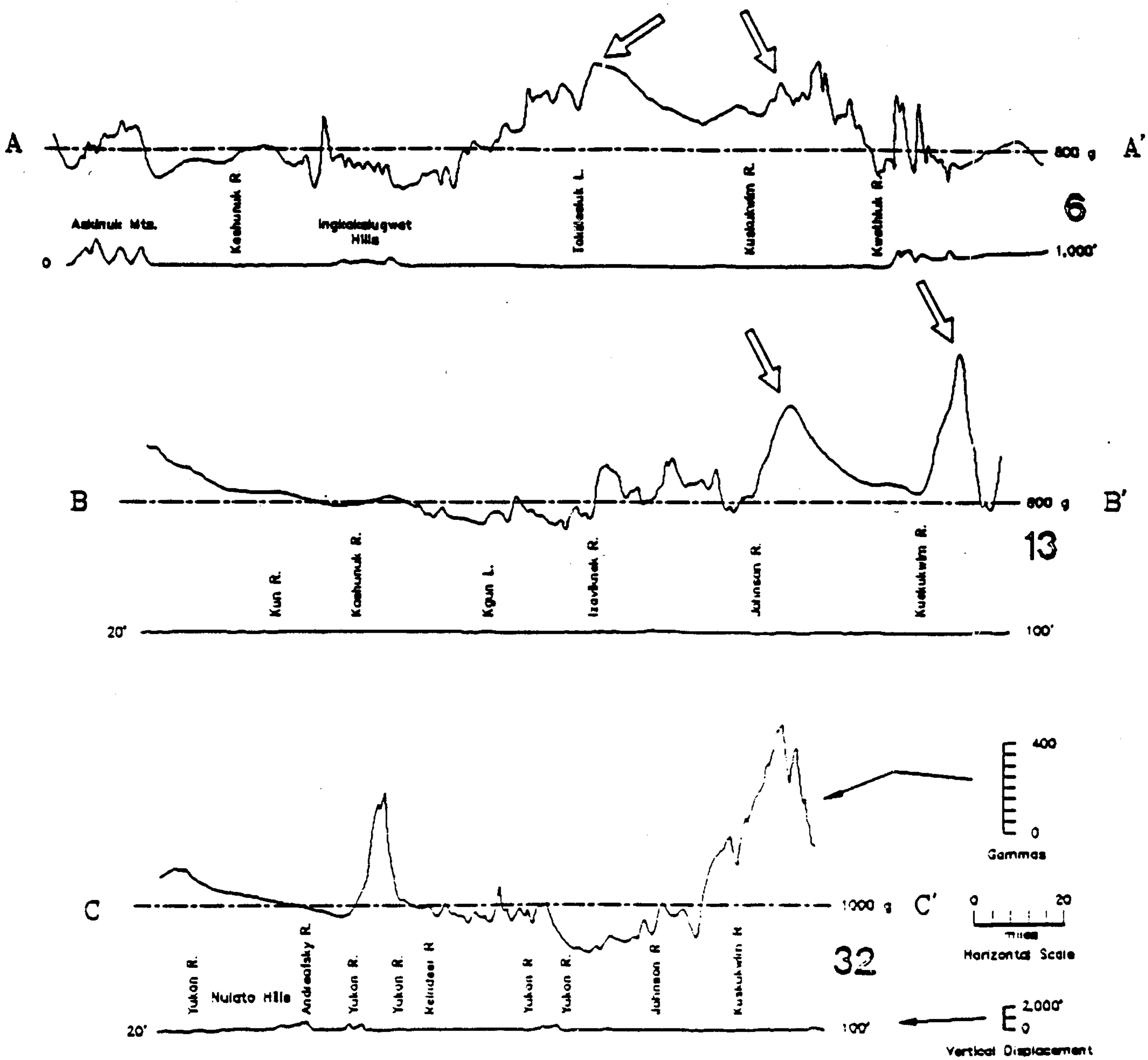


Figure 3. After Dempsey and others, 1957

systems; the Iditarod-Nixon Fork, the Denali-Farewell, and the Mulchatna, which divide the Kuskokwim Group rocks into three geographic basins; the Iditarod basin, the Central Kuskokwim basin, and the Nushagak basin (Decker and others, in preparation, 1987). A fourth depositional basin is recognized; the Bethel basin, underlying the Yukon-Kuskokwim lowland west of the Central Kuskokwim basins and southwest of the Iditarod basin. The east and west basin margins are defined by two northeasterly trending magnetic lineaments (plate 5). The geologic relationship between these basins is unclear, although the lithology appears to be similar in all of them. The Kuskokwim Group deposited in the Bethel basin will be described separately from well data.

The Kuskokwim Group rocks in the central Kuskokwim basin overlie the Kilbuck, Goodnews, Togiak (Hagemeister subterrane) Terranes in the northern Goodnews and Bethel quadrangles. It consists of marine proximal turbidite with shallow marine and possibly nonmarine fluvial strata. The sediments are derived locally from the underlying terranes. The facies relationships suggest rapid deposition within a structurally subsiding continental trough (Decker and others, in preparation, 1987; Hoare, 1961). The well-indurated rocks are complexly faulted and folded. The Kuskokwim Group is not known to overlap the Nyac Terrane or the Kulukak subterrane of the Togiak Terrane (Decker and others, in preparation, 1987). Along the most eastern edge (Nushagak basin) of the basin, strata similar to the Kuskokwim Group crop out and may extend beneath Quaternary deposits along the eastern edge of the Nushagak lowland to underlie the Nushagak Peninsula and overlie the older rocks of the Togiak (Kulukak subterrane) Terrane.

The basal Kuskokwim Group of the Central Kuskokwim basin (in the Togiak and eastern Yukon-Delta NWR) consists of massive (500 m thick), deep marine conglomerates that overlie the structurally disrupted Goodnews Terrane (including the Valanginian Eek Mountain belt turbidite unit) (Murphy, 1987, Hoare and Coonrad, 1983). The conglomerates thin to the northeast from a shallow-marine (possibly nonmarine or near-sea-level) to a deep-marine conglomerate that outcrops at Greenstone Ridge and along the Kisaralik anticline and covers the contact of the Goodnews and Togiak Terranes (Box and Murphy, 1987; Hoare, 1961).

The Kuskokwim conglomerates overlie the Eek Mountain belt in angular unconformity; they consist of amalgamated, matrix supported, poorly sorted pebble- to pebble-conglomerate bed with subangular and well-rounded clasts of multicolored chert and tuff, limey siltstone, argillite, schist and gneisses, with massive and foliated greenstone in a matrix of fine-pebbly sandstone. The basal conglomerate is conformably overlain by a thick section of black, micaceous shale that grades upward into several kilometers of thin-bedded sandstone (graywacke), turbidite, and shale (Murphy, 1987; Hoare and Coonrad, 1983).

The basal conglomerates at Greenstone Ridge and the Kisaralik anticline (approximately 40 km north-northeast along the strike with the Eek Mountain belt) overlie the foliated metamorphic rocks of the Goodnews Terrane; with a lower conglomeratic section of shallow marine or near sea-level depositional base and an upper conglomeratic section of deep marine origin. The lower section at Greenstone Ridge consists of clast-supported, rounded-boulder conglomerates with a sandstone matrix. It is overlain by a pebbly conglomerate with dispersed well-rounded boulders; which, in turn, is overlain by a coarse-grained, cross-bedded sandstone and gravel that grades upward into coarse-grained sandstone and cobbly sandstone. In the Kisaralik anticline area, the upper basal part of the Kuskokwim Group consist of shallow marine deposits of coarse-grained, crossbedded sandstone with channelized lag deposits of tuffaceous chert-cobble conglomerates, with horizontal burrows and Inoceramus sp. prism. This is overlain by matrix-supported, pebble to cobble conglomerates, which, in turn, are overlain by thin-bedded sandstone (graywacke) and shale with gravel interbeds and flute-casts that is overlain by an amalgamated clast- and matrix-supported cobble conglomerate. Both sections are overlain by several kilometers of thinly-interbedded sandstone and shale that overlie or possibly interfinger with volcanogenic rocks of the Togiak Terrane (Box and Murphy, 1987). Hoare (1961) briefly described some nonmarine strata at the north end of Greenstone Ridge that consists of interbeds of shale and fine- to coarse-grained crossbedded sandstone and pebbly conglomerate that contained abundant carbonized wood fragments and thin beds of coal.

Murphy (1987) interprets the Kuskokwim Group deposits at Eek Mountain as submarine-channel-canyon facies that onlap onto the metamorphic rocks of the Goodnews Terrane, while Kuskokwim deposits on Greenstone Ridge and the Kisaralik anticline area may record a shallow to deep-marine transition.

Upper Cretaceous

The Upper Cretaceous (Campanian to Maestrichtian) nonmarine sedimentary rocks of the Summit Island Formation (Hoare and others, 1983) occur as isolated coastal exposures in the Togiak Bay area and unconformably overlie the Togiak Terrane (including the Hagemeister and Kulukak subterranes). It consists of well-rounded, pebble-cobble conglomerates (200 m) with clasts (derived from the underlying Togiak Terrane) of chert, argillite, and rare schist and plutonic clasts. The conglomerates are overlain by a carbonaceous shale with interbedded, channelized sandstone (800 m), that fines and thins upward, and thin seams of coal. The rocks are well indurated and mildly deformed. The Carbonaceous Shale unit is the dominant lithology of the formation (Hoare and others, 1983; Box, 1985a). The Summit Island Formation is depositionally overlain by 3 km of volcanic and volcaniclastic rocks of latest Cretaceous age (Box, 1985a). Tertiary sedimentary rocks are unknown within this area.

Quaternary Deposits

Quaternary basalt flows, known as the Togiak basalts (Hoare and Coonrad, 1980), underlie most of the lower Togiak Valley and compose the next youngest formation within the area. The basalts are divided into the lower unit of low-lying horizontal flows less than 100 m thick and the upper unit, about 300 m thick, which is regarded by Hoare and Coonrad (1978a, 1980) as a tuya, a rare geological feature of a subglacial volcano. Glacial outwash deposits conceal most of the Togiak basalts. Where exposed, the base of the Togiak basalt flow rests unconformably upon the Mesozoic volcanic and volcaniclastic rocks of the Togiak Terrane.

Unconsolidated Quarternary deposits cover approximately one-third of the area (Hoare, 1961). These consist of glacial deposits of silts, sands, gravels of unsorted glacial drift, glaciofluvial and morainal deposits. Glacial outwash deposits cover the upper part of the Nushagak Peninsula and the Togiak Valley. There they form terraces and outwash fan-plain deposits of poor to well-sorted sand and gravel with a few dispersed boulders. Thickness of glacial deposits range from a thin veneer to at least 50 m (Hoare, 1961), but are probably much thicker on the Nushagak Peninsula.

Holocene deposits of mud, silts, sands, gravel, and boulders of flood plain alluvium occur along present day streams. Also, bog deposits and loess deposits occur throughout the area, as well as modern-day estuarine and beach deposits

Yukon Delta NWR, Lowlands

The underlying Yukon-Kuskokwim lowland contains two distinct sedimentary basins, the Bethel on the east and the Lower Yukon basin on the west. Because there is very little geologic information available for this area, much of the geology is inferred from limited aeromagnetic data and from the regional surface geology of the surrounding area. One exploratory well (Napatuk Creek No. 1), drilled in the Baird Inlet quadrangle (Sec. 34, T. 7 N., R. 78 W., SM) in 1963 by the Pan American Petroleum Corporation (now AMOCO), was plugged and abandoned. It had no shows of oil, but insignificant amounts of coal were reported.

The Bethel basin is located within the lower Kuskokwim River drainage system. It is a narrow northeast-trending sedimentary basin as indicated by aeromagnetic data (Godson, 1983; Decker and Karl, 1977a; Alaska Division of Geology and Geophysics, 1973a; Dempsey and others, 1957). The basin is flanked by two northeast-trending, magnetic lineaments (plate 5). The absence of high frequency magnetic anomalies in the vertical magnetic field (figure 3, profile a, b, between the arrows) is interpreted to outline the Bethel basin. The western magnetic high is interpreted as a basement high that separates the Bethel basin from the Lower Yukon basin and appears to be limited by faulting. The eastern magnetic high coincides with the Jurassic andesitic Nyac Terrane. On the vertical magnetic field (figure 3, profile a, b), the steepness of the eastern peaks (arrows) of the magnetic survey suggests that the basin is in fault contact with the Nyac Terrane. Farther to the northeast, higher frequency magnetic anomalies indicate that the basin may shallow to the northeast or truncate against a basement high (figures 2 and 3, profile c).

The Pan American Napatuk Creek No. 1 well was drilled to a total depth of 14,910 feet (4,545 m) on the southwestern margin of the Bethel basin. It penetrated approximately 2,000+ feet (610 m) of Tertiary sediments, predominantly marine siltstone with interbedded silty sandstone, and 12,800 feet (3,900 m) of moderate-to-well-indurated Cretaceous sedimentary clastics of the Kuskokwim Group. The general lithologic character of the Napatuk well as described predominantly from ditch samples, cores, and well logs is depicted in figure 4.

Generally, the Kuskokwim Group penetrated by the Napatuk Creek well is characterized as interbedded sandstone and shale. The sandstones are poorly sorted, fine-grained graywackes; the shales are generally silty and micaceous and with abundant carbonaceous plant debris; leaf fossils occurring between the bedding planes in the shaley interval (indicated by core data) have been dated as Turonian (Early Late Cretaceous) (Spicier, personal communication, 1987). Thin-bedded coal and lignite are also common throughout the shaley intervals. Near the base of the well, 12,500 feet (8,810 m) - 14,910 feet (4,545 m), is a predominantly massive sandstone containing Inoceramus prisms of Late Cretaceous age. Between 4,796 feet (1,462 m) and 5,308 feet (1,615 m) are predominantly volcanicly-derived sediments of welded tuff and intrusive quartz diorite.

The poorly-sorted sandstone (graywacke) and the dominant herbaceous material from the Napatuk Creek well indicate rapid deposition for the Kuskokwim Group in the Bethel basin from proximal sources. This is comparable to age-equivalent Kuskokwim strata of interbedded graywacke and shale, exposed further to the northeast near Aniak and described by Decker and Hoare (1980) as prodelta or turbidite deposits and interpreted as rapid deposition from proximal sources. The upper, finer-grained section of interbedded graywacke and shale sequence described by Box and Murphy (1987) in the nearby Kilbuck Mountains is, also, comparable to the Kuskokwim strata penetrated by the Napatuk Creek well.

The overlying Tertiary section is predominantly marine siltstone with some interbedded, silty sandstone. Palynological analyses of the ditch sample for the Tertiary section revealed that from 760 feet (232 m) to 920 feet (280 m) is Pliocene, from 920 feet (280 m) to 1,560 feet (475 m) is Late Miocene/Early Pliocene, and from 1,560 (475 m) - 2,100 feet (640 m) is undifferentiated Tertiary. Pleistocene and Holocene deposits overlie the Tertiary rocks from 0-760 feet (232 m) (Mobil Oil Corporation, 1982).

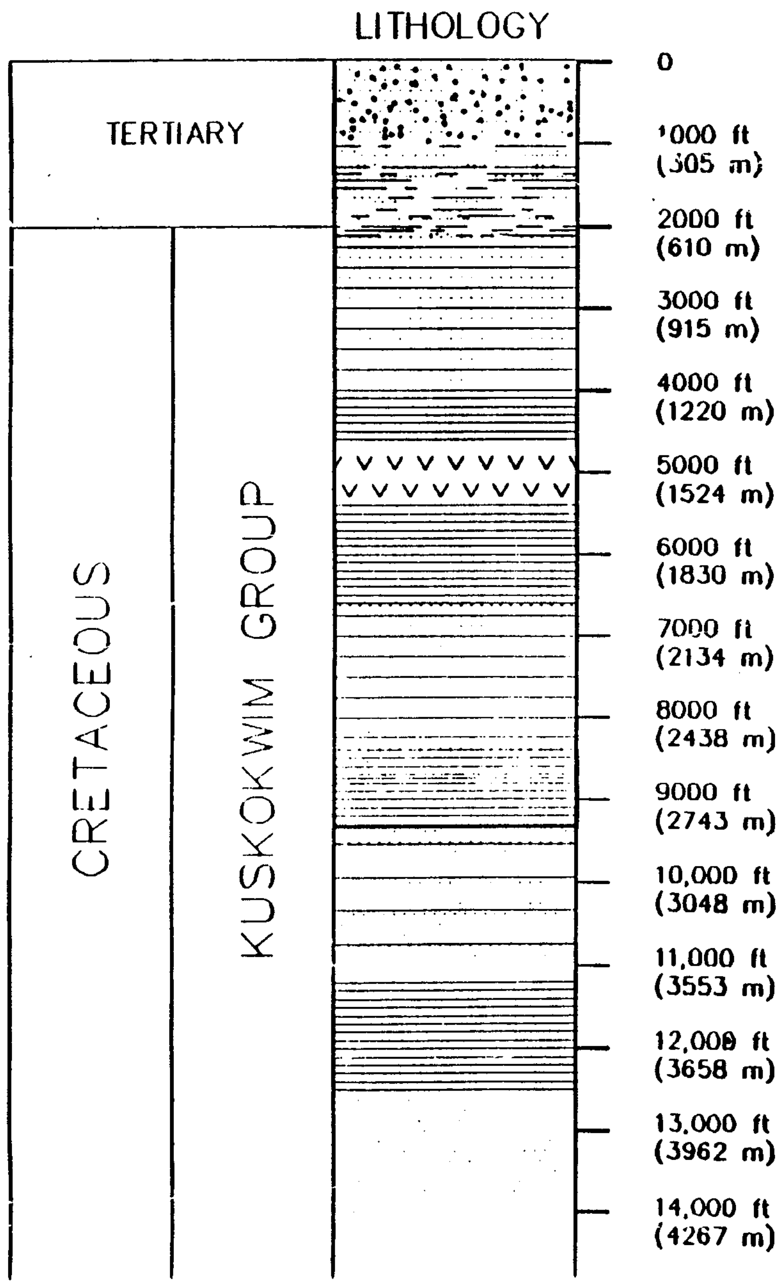
GENERALIZED STRATIGRAPHIC COLUMN

Figure 4.

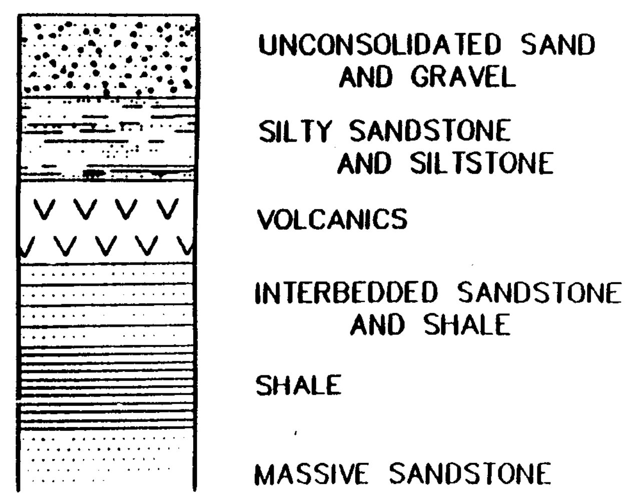
[See text for discussion]

Napatuk Creek #1
(sec.34, T. 7 N., R. 78 W.)

Pan American
Petroleum Corporation



EXPLANATION



Lower Yukon Basin

The Yukon-Koyukuk basin trends northeast (figure 5). The southwest extension of this basin (called the lower Yukon basin) crops out along the lower Yukon River between Mountain Village and Marshall and has been inferred to extend beneath the Yukon-Kuskokwim lowland (Nilsen and Patton, 1984; Patton, 1973). The basin is underlain by Neocomian (Early Cretaceous) andesitic volcanic and volcaniclastic rocks of the Koyukuk Terrane at least 1,500 m thick (Jones and others, 1984; Patton and Box, 1984; Patton and Moll, 1984). These rocks are known to crop-out on both sides of the basin in the Black and Kwiguk quadrangles and are overlain by marine to nonmarine Albian to Cenomanian (early Late Cretaceous) sedimentary clastics as much as 8,000 m thick (Hoare and Condon, 1966; Patton and Moll, 1984). Farther to the east in the vicinity of Marshall, the Koyukuk Terrane overlies older Paleozoic or Mesozoic metamorphosed mafic volcanic and metasedimentary rocks containing radiolarian chert (Box, personal communication, 1987; Hoare and Condon, 1971)

These older rocks mark the edge of the basin and are on trend and appear to correlate with the magnetic lineament (plate 5) along the western margin of the Bethel basin. These rocks appear to extend beneath the refuge to form the basement high that separates the two basins. The mafic volcanic and metasedimentary rocks have been correlated to the older Paleozoic to Precambrian pelitic schist, quartzite, and granitic metamorphics of the Ruby Terrane (RB?, plate 3) (Jones and others, 1984). However, the Paleozoic and/or Mesozoic mafic rocks may be uplifted basement rocks of the Koyukuk Terrane, rather than rocks of the Ruby Terrane (Box, personal communication, 1987). The Ruby Terrane borders the southeast margin of the Yukon-Koyukuk basin (RB of plate 3).

Albian to Cenomanian (early Late Cretaceous) sedimentary clastics overlie the Koyukuk Terrane rocks and crop-out in a northeast-trending belt along the lower Yukon River between Mountain Village and Pilot Station, parallel to the regional strike of the basin. The rocks appear to extend to the southwest, to underlie the Yukon Delta NWR lowland (corresponding to the low frequency anomalies (plate 5, figure 3)), and to reemerge in outcrops on Nelson and Nunivak Islands.

The Albian to Cenomanian clastics exposed between Mountain Village and St. Marys consist predominantly of volcanogenic graywackes interbedded with siltstone and shales which contain abundant carbonaceous plant debris and thin bedded coals. The sandstone are well-indurated and are complexly folded and faulted, with some beds isoclinally folded (Hoare and Condon, 1966). Between St. Marys and Pilot Station, the sandstone beds and noncalcareous to calcareous medium- to fine-grained sandstone (graywacke) crop out. The sandstones are hard, well indurated, and interbedded with black to dark gray siltstones and are commonly micaceous. The rocks commonly show ripple marks, crossbedding and mud cracks, and contain abundant plant debris. They are

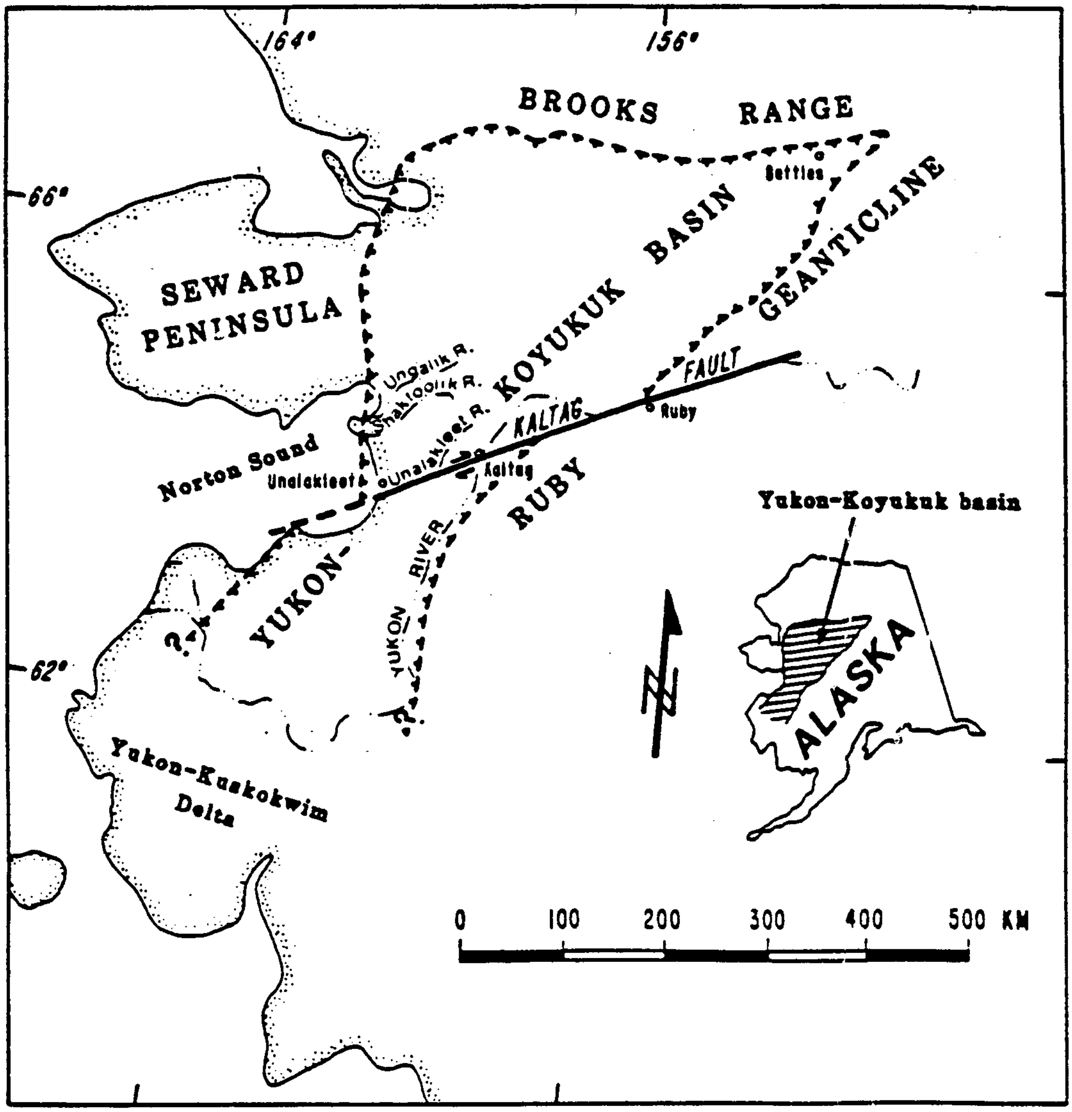


Figure 5.-Index Map of the Yukon-Koyukuk Basin. Adjacent to the Yukon Delta NWR (from Nilsen and Patton, 1984).

equally deformed and faulted, posing difficulty in establishing stratigraphic or structural relationships. The outcrop probably reflects structural repetition by faulting and folding, although some may represent stratigraphic succession (Hoare and Condon, 1966).

The Nunivak and Nelson Island Cretaceous exposures occur as isolated outcrops overlain by Quaternary basalts. These Cretaceous clastic rocks consist of interbedded graywacke and clayey siltstone with localized pebbly conglomerates. The graywackes are fine- to coarse-grained and composed largely of volcanic rock fragments in a clay matrix. Most of the sections on Nelson Island are clayey siltstones in contrast to the hard-sandstone beds exposed to the northeast along the Yukon River. The rocks are folded and faulted as well (Appendix 1 contains measured stratigraphic sections and field note descriptions for the Yukon River and Nelson Island sections).

Granodiorite plutons which intrude the Cretaceous strata to the northeast and along the western edge of the basin are interpreted as Late Cretaceous in age. The granodiorite pluton that makes most of the Askinuk Mountains contains interbedded sandstone and siltstone exposed as roof pendants, which have been altered to hornfels. This pluton, as suggested by geophysical data (Hoare and Condon, 1968), may be part of a larger intrusive body underlying as much as 1,400 square miles. This may account in part for the western-most high magnetic lineament (plate 5, figure 3). Also, the Koyukuk Terrane volcanic rocks, as well as Quaternary basalt flows which tend to have higher magnetic susceptibility, are exposed near the surface at the northwestern margin of the basin.

Tertiary sedimentary rocks are not exposed within the refuge area; however, the Napatuk Creek well penetrated approximately 2,000 feet (680 m) of Tertiary sediments. Therefore, it seems likely that similar Tertiary strata may underlie the lower Yukon basin as well. Also, the Tertiary sedimentary clastic rocks that underlie the Norton Sound basin are interpreted to extend beneath the Yukon River Delta (Fisher and others, 1981) and probably pinch out against the andesitic volcanic rocks of the Koyukuk Terrane (figure 6A). The remaining refuge is overlain by scattered basalt flows and Quaternary deposits.

The reservoir quality of thick Cretaceous rocks exposed along the Yukon River (described above) are poor, because they are considerably deformed and relatively impermeable. Porosity and permeabiliy data reported by Lyle and others (1982) run less than 10 percent porosity and no more than two millidarcies for permeability. Also, low values were reported for the Cretaceous exposed on Nunivak and Nelson Islands as well.

Structures

The rocks in the Togiak and eastern Yukon Delta NWR are severely deformed by complex folding and faulting; therefore, only a brief outline will be presented here. This uplifted region has been compressed into many folds that range from large complex folds, several miles across to small, tight,

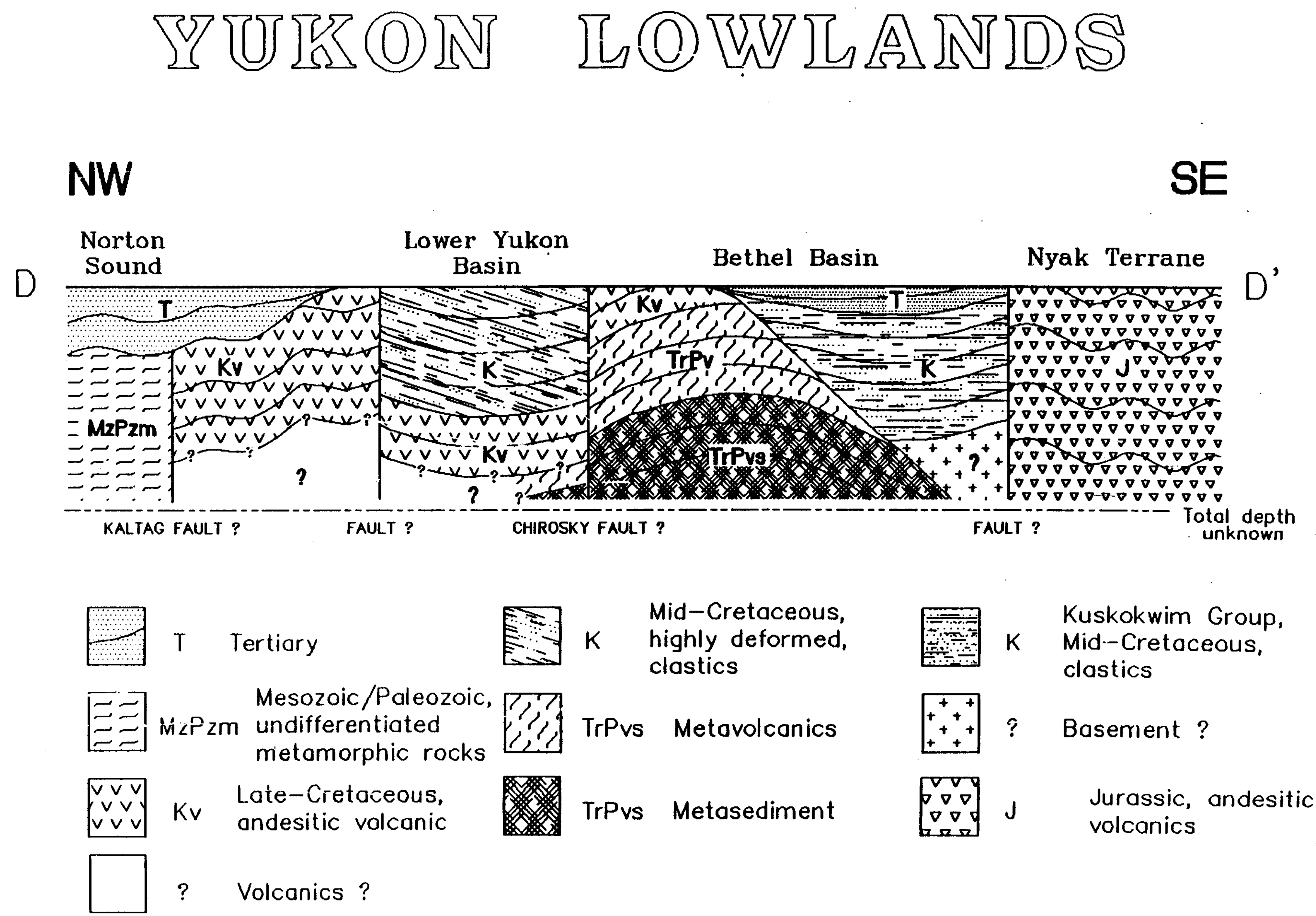


Figure 6a., Generalized Subsurface Geology

disharmonic folds. In the western part of the area, the Eek Mountain and Kisaralik anticlines are several miles across and both plunge gently northeastward; and are cut by numerous steep dipping reverse faults (Box and Murphy, 1986; Hoare, 1961; Hoare and Coonrad, 1959a;). These two structural features are actually composed of many smaller folds that have been superimposed upon larger folds, i.e., the structures are anticlinoriums. East of the Kisaralik anticline is the Salmon River syncline which also plunges to the northeast. The limbs of the syncline are clearly defined by the dip of the strata. Farther to the north the axis of the structure is disrupted into many small, tight, disharmonic folds (Hoare, 1961). In the southwest part of the area (plate 5), the strata of the Goodnews Arch are compressed into broad anticlinal and synclinal folds that plunge gently to the northeast. The broad folded rocks are superimposed on older tightly compressed folded strata (Hoare, 1961). Most of the structures have been faulted by numerous northeast-trending faults that divided the structure into many fault slices and fault blocks that range from a few hundred meters to several hundred kilometers (Hoare and Coonrad, 1978b, d). The principle faults are Togiak-Holitna faults, Goodnews, and Golden Gate faults, they are high-angle faults with a strike-slip component that dips to the southeast along with associated thrust faults. Most of the deformation is related to subduction of oceanic plates and the collision of exotic terranes with the continent.

The structural architecture of the underlying basins within the Yukon Delta NWR lowland are largely undefinable without access to the seismic lines that have been shot in the area. However, for the lower Yukon basin, surface exposures of the mid-Cretaceous clastics along the lower Yukon River (between Mountain Village and Pilot Station) are considerably deformed. The exposures are northeast-trending and characterized as isoclinal folds that are overturned to the southeast. The structures are cut by closely spaced, high-angle reverse(?) faults. Hoare and Condon (1966) suggest that the pattern and intensity of folding indicates southeast-directed, compressional stresses.

The granodiorite plutons that are exposed in the western margin of the refuge appear to be part of a larger underlying pluton as suggested by magnetic data (plate 5, figures 2 and 3, profiles a and b). The exposed plutons have magnetite as an accessory mineral which produces large magnetic anomalies. This, with the magnetic lineament along the westernmost margin of the refuge, suggests that the granodiorite pluton is extensive or part of several underlying intrusive bodies along the margin of the lower Yukon basin.

The underlying structure for the Bethel basin again is largely unknown. Although cores recovered from the Napatuk Creek well Tertiary and Cretaceous interval were generally described as flat bedded, with an average dip measurement of less than 15 degrees for most beds. Slickensided surfaces from cores in the Cretaceous interval were reported, especially from 9,392 feet (2,838 m) to 9,406 feet (2,843 m) where several mineralized shear planes occurred, indicating possible fault. The correlative Cretaceous rocks (Kuskokwim Group) to the Napatuk well are exposed to the east in the Kilbuck

Mountains and northeastware in the vicinity of Aniak are moderately to highly deformed by faulting and folding, which suggests that the Bethel basin may have a complicated structural architecture.

Wallace (personal communication, 1987) suggested that the Bethel basin has been faulted into its present position along the northeast-trending right-lateral fault, i.e., the Iditarod-Nixon Fork fault and Susulatna lineament.

Aeromagnetic data indicates a sharp linear boundary between the northwest flank of the Nyac Terrane and the basin's eastern flank. This is suggestive of a steep fault, which may be the continuation of the Iditarod-Nixon Fork fault. The Kuskokwim Group in the northeast has been shown to be displaced southwestward approximately 80 to 110 km along the Iditarod-Nixon Fork fault (Grantz, 1966; Gemuts and others, 1983). This southwestern displacement may also be related to the Bethel basin, but there is no concrete evidence to support this.

The geologic cross sections (figure 6A, B) are highly idealized and interpretive schematic diagrams constructed primarily from aeromagnetic data, well information, and exposures of lithological units along the north-northwest margin of the refuge. The geology is probably much more complex than what is shown here.

Tectonic and Geologic History

The terranes within the Togiak and eastern Yukon Delta NWRs are interpreted by Box (1985a) to be an oceanic volcanic arc-trench complex formed during the Late Triassic to Cretaceous time. These terranes reflect episodic magmatism and accretion of the volcanic arc complex (Togiak Terrane) with a growing subduction complex (Goodnews Terrane), culminating in arc continent collision. The Kilbuck Terrane is interpreted as a cratonal fragment against which the volcanic arc collided in Late Cretaceous time. The Nyac Terrane is thought to be a repeated segment of the Togiak Terrane. Figure 7 schematically illustrates the tectonic history summarized here from Box (1985a).

The Togiak Terrane's earliest history was initiated by Upper Triassic arc volcanism, building to sea level by early Jurassic time. Subduction of the Goodnews Terrane, using present day coordinates, occurred on the northwest flank of the volcanic arc (Hagemeister Subterrane). Each subterrane of the Goodnews Terrane was structurally emplaced against and beneath the volcanic arc, creating imbricately stacked subduction complexes of accreted oceanic plate lithology (figure 7). The Cape Pierce and Platinum subterranes were obducted in early Jurassic time. The Cape Pierce subterrane is interpreted as an "exotic oceanic plateau or relatively thickened oceanic crust constructed of mafic volcanic and interbedded limestone traveling on the incoming subducting plate" (Box, 1985a). The Platinum subterrane is a remnant of the

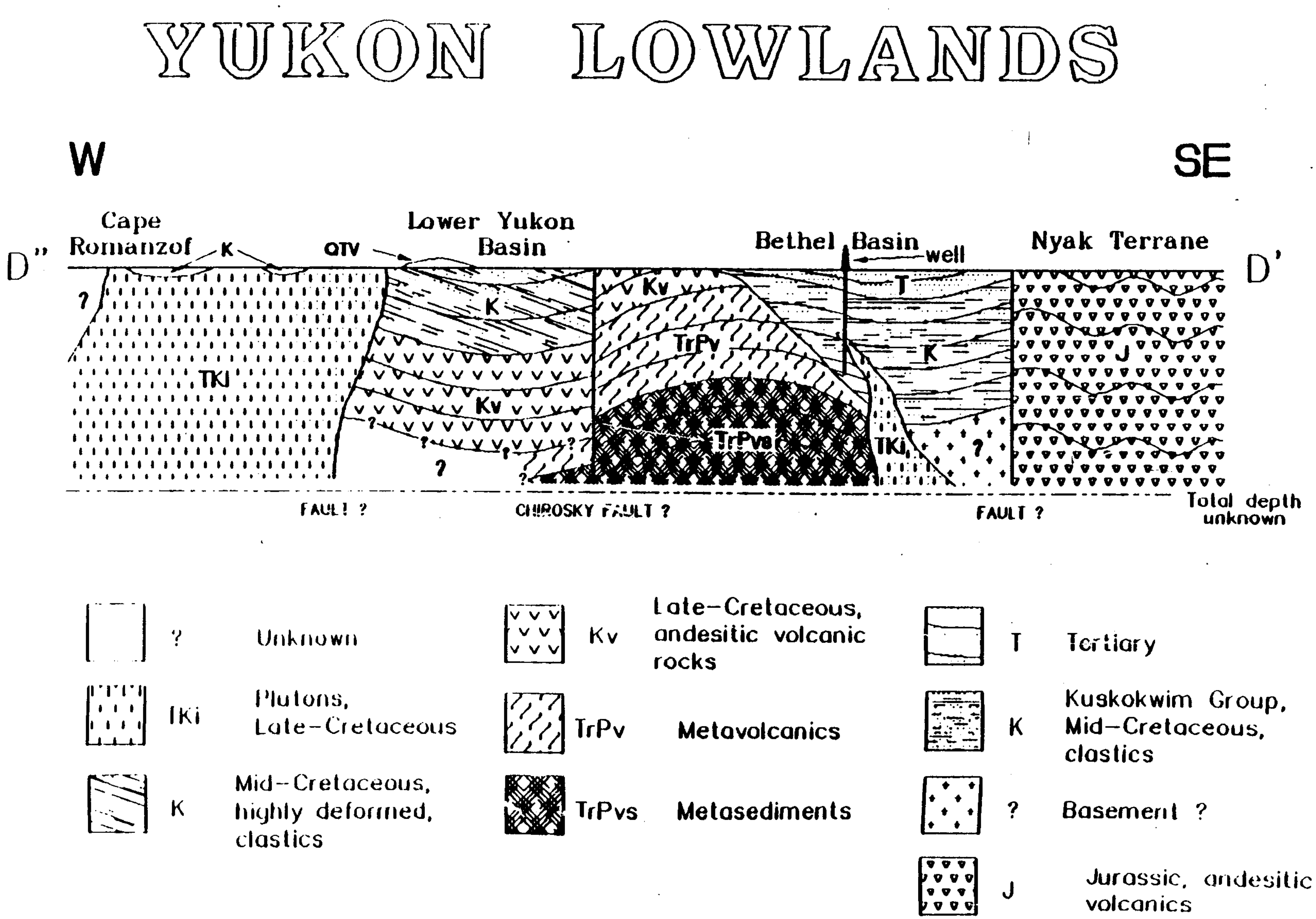


Figure 6b., Generalized Subsurface Geology

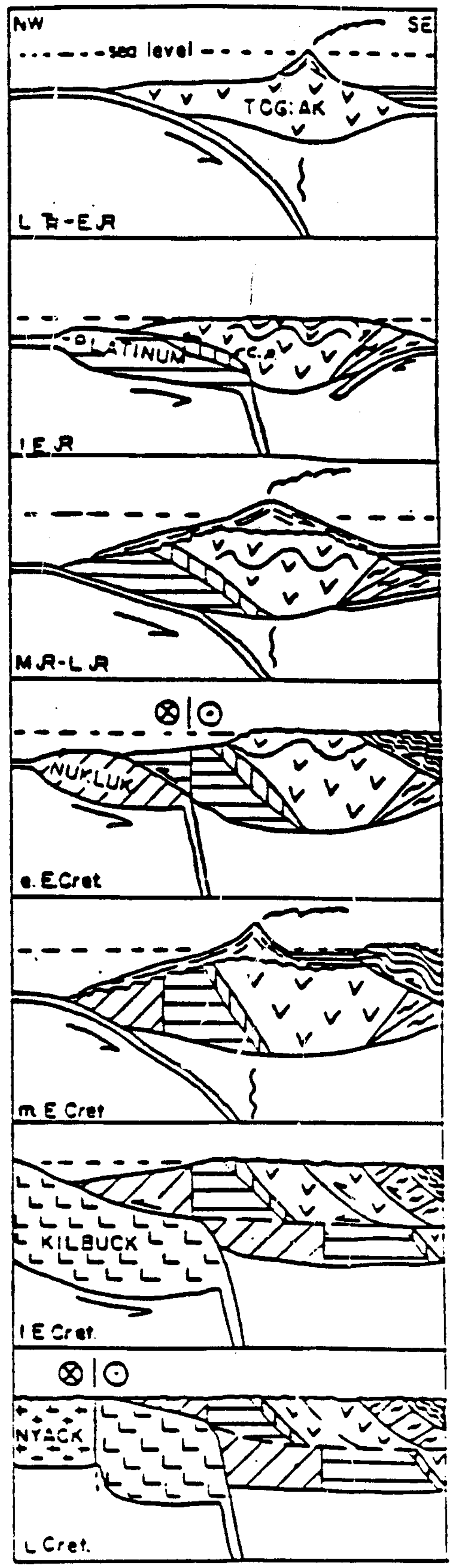


Figure 7.-Schematic Diagram of the Tectonic Evolution of the Togiak Area (from Box, 1985a).

colliding oceanic plateau. The Cape Pierce subterrane was metamorphosed to a glaucophane-lawsonite metamorphic assemblage. A back arc setting formed in response to the collision of the oceanic plateau. Subsequently, the arc was intruded by granitic and ultra mafic magmas, followed by rapid uplift of the arc platform. The Kulukak subterrane volcaniclastics were deposited in the back arc setting (southeast of the Hagemeister Subterrane) (figure 7) during middle Jurassic time.

In the early Cretaceous, the Nukluk subterrane of the Goodnews Terrane is also considered to be an exotic oceanic plateau (unrelated to the Cape Pierce subterrane); its Devonian, Permian, and Upper Triassic limestone was structurally emplaced against and beneath the northwest flank of the volcanic arc. Major deformation events resulted in the northwest-directed thrusting of the back arc sediment on to the arc platform. By middle Cretaceous, renewed arc volcanism resulted from subduction along the northwest flank of the amalgamated Nukluk Subterranes, witnessed in the final convergence with the North American continent. The Precambrian metamorphic rocks of the Kilbuk Terrane is interpreted by Box (1985a) as a cratonal fragment (probably of North American affinity) that partially underthrust the amalgamated Togiak and Goodnews Terranes sometime in the Middle Early Cretaceous time. This resulted in the metamorphism of the Kilbuck and Goodnews Terranes to a greenschist facies (locally blueschist) and cessation of arc volcanism.

Subsequently, uplift of metamorphosed Kilbuck and western Goodnews Terranes in late Early Cretaceous provided a sediment source for the deep Kuskokwim basin (central Kuskokwim basin) between the uplifted collisional suture and the Togiak Volcanic Terrane (Box and Murphy, 1987); at the same time the Kuskokwim Group was being deposited in the Bethel basin. Sedimentation of the Kuskokwim Group continued through early Late Cretaceous (Turonian) time with a gradual shallowing of the basins. Strike-slip tectonics during the deposition of the Kuskokwim Group have been suggested (Pact and Wallace, 1984), but cannot be fully demonstrated here.

The Nyac Terrane is thought to be a repeated segment of the Togiak Terrane that was once continuous, or "end-to-end," as a single volcanic arc. Late Cretaceous, right-lateral strike-slip movement may have sliced the amalgamated Kilbuck-Goodnews-Togiak Terranes resulting in the repeating of the arc terrane (Box, 1985a).

The Yukon-Koyukuk Province (also Yukon-Koyukuk basin) tectonic development is that of an arc-continent collision. The Koyukuk Terrane consisting of Late Cretaceous andesitic volcanic and volcaniclastic rocks was deposited by the volcanic arc complex. The volcanic arc was probably built upon late Paleozoic early Mesozoic oceanic crust (Harris and others, 1987). By late Early Cretaceous, the volcanic arc complex collided with the continental margin thrusting oceanic Angayucham Terrane (consisting of Mississippian to Jurassic basalt, chert, and minor limestone) over the continental margin consisting of Ruby Terrane (Harrison and others, 1987).

Subsequently, during the early Late Cretaceous (Albian to Cenomanian), arc volcanism ceased and terrigenous sediments from the rising borderland began infilling the basin; this was followed by latest Cretaceous granitic intrusion.

Figure 8 outlines the tectonic evolution of the Yukon-Koyukuk basins, and shows the relationship of each terrane described above. The relationship of the underlying basement high in the Yukon Delta NWR to the tectonic activity of arc continent collision is uncertain.

By the end of the Cretaceous, the tectonic emplacement of the various terranes in the area was completed. Normal sedimentation and erosion probably continued, from the uplifted highland area, filling in the lowland area.

During the Late Miocene to Pleistocene marine transgression/regression occurred over the Yukon Delta NWR's lowland area (as indicted by occurrence of Miocene to Pleistocene marine siltstone and sandstone penetrated by the Napatuk well). Pleistocene glaciation occurred in the Togiak area, with earliest glaciation beginning about 2 million years ago, covering much of the refuge area. The last period of glaciation ended about 15,000 years ago (Mertie, 1976).

During Quaternary time in the Yukon Delta NWR area, the Yukon-Kuskokwim rivers deposited voluminous amounts of sediments over the lowland area. The Yukon-Kuskokwim Rivers exhibit a complex history of marine and nonmarine deposition (Pewe, 1975). Renewed volcanism during the Late Tertiary and Quaternary formed olivine basalt flows in the Togiak and Yukon Delta refuges.

Geochemistry

Lyle and others (1982) collected a total of 28 samples within the Yukon Delta NWR, from Nelson and Nunivak Islands, and from along the lower Yukon River for source rock analyses. Their results are summarized on table 2. The type kerogen reported for all 28 samples were gas prone, woody-coaly-herbaceous material, with an average total organic carbon of 0.24 percent. The total C_{15}+ extracts were composed largely of asphaltenes (nonhydrocarbon). The Thermal Alteration Index (TAI) ranges from 2 to 3+, which is considered to be thermally mature for the generation of hydrocarbons; however, the possibility of a commercial occurrence (adjacent to the sample site) is minimal, based upon the sparseness of organic content (Lyle and others, 1982).

Mobil Oil Corporation (1982) conducted visual kerogen and vitrinite reflectance studies of the Napatuk Creek Well No. 1 (there were no total organic carbons (TOC) reported from these studies). The Kerogen analysis for the entire well is described as cellulosic, gas- prone type kerogen. The vitrinite reflectance (Ro) studies indicated the Tertiary section from 60 feet (18 m) to 2,130 feet (644 m) is thermally immature. The Cretaceous interval, from 2,130 feet (644 m) to 5,100 feet (1,540 m), is thermally mature (TAI 2^{+}

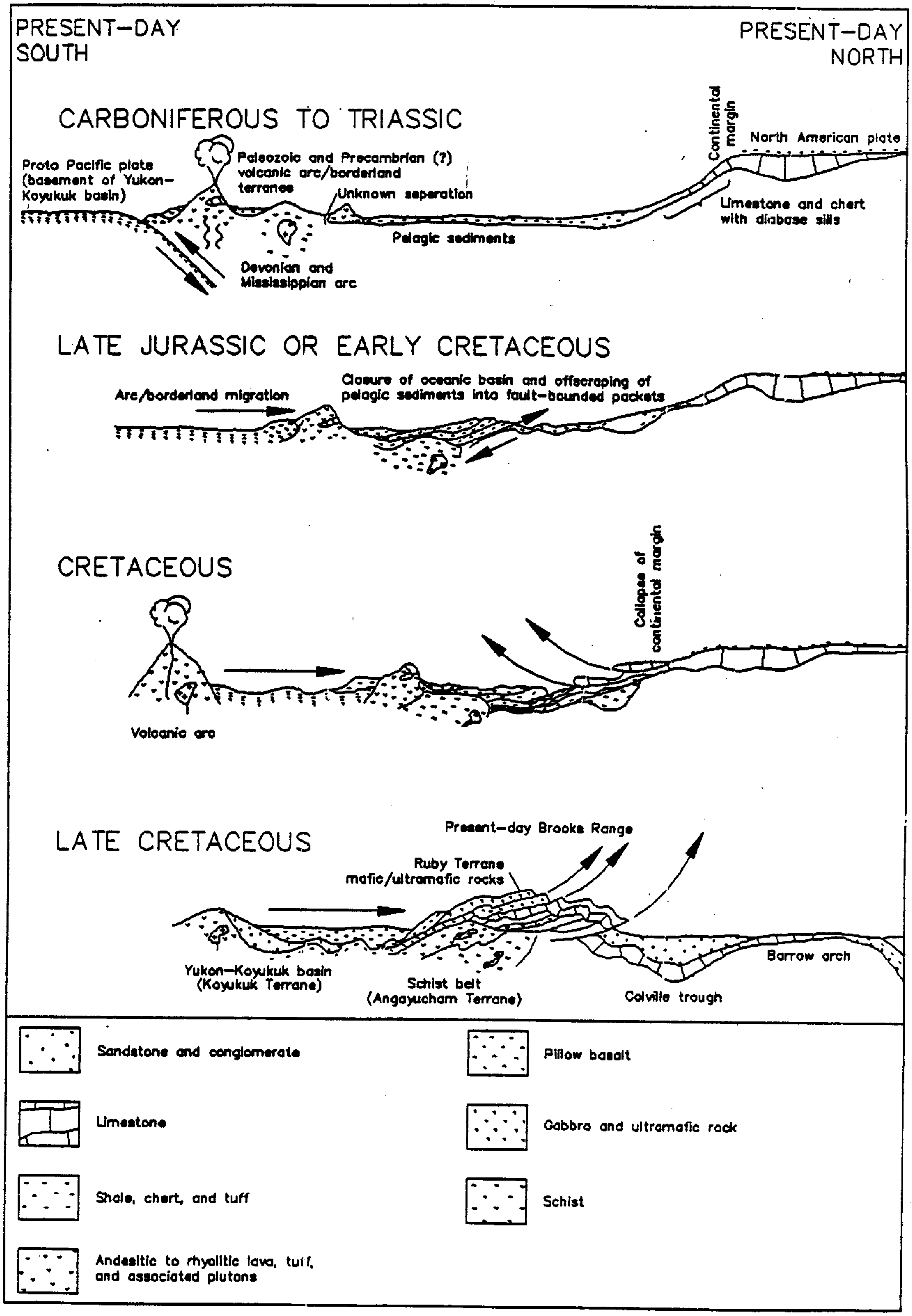


Figure 8. A series of sketches showing the relationships between the Koyukuk, Angayucham, and Ruby terranes (after Churkin et al., 1979).

to 3^-); from 5,100 feet (1,540 m) to 5,700 feet (1,723 m), igneous activity produces a vitrinite reflectance anomaly; from 5,100 feet (1,540 m) to 14,870 feet (4,495 m), is over- mature for liquid hydrocarbon generation. However, from 6,000 feet (1,814 m) to 9,600 feet (2,900 m), wet gas or condensate would probably survive, with the reported vitrinite reflectance value for the low gray Ro mean ranging from 1.44 to 1.99 percent, and the first Ro high gray mean (same depth interval) ranges from 2.34 to 2.46 percent. The Thermal Alteration Index ranges from 3^- to 3^+. Below 9,600 feet, methane ~~gas is only~~ likely to survive (Mobil Oil Corporation, 1982).

Description of Oil and Gas Resources

There are only two areas within the State of Alaska that have current hydrocarbon production, the Arctic North Slope Prudhoe Bay and Cook Inlet basin, with neither of the two being related to the Togiak and Yukon Delta NWRs. either geologically, geographically

Known Oil and Gas Field Locations

There are no known oil and gas fields within the Yukon Delta or Togiak NWRs and surrounding area. Although oil and gas seeps have been reported by local residents in several locations along the Yukon River bordering the Yukon Delta NWR. These are regarded as doubtful by the U.S. Geological Survey; at some localities, iron-oxide films on water was probably thought to be oil (Miller and others, 1959).

In 1961, the Pan American Petroleum Corporation drilled the Napatuk Creek No. 1 well (Sec. 34, T7N,R38W), approximately 35 miles (56 km) southwest of Bethel. This is the only oil and gas exploratory well in either refuge area. It was plugged and ~~abandoned in 1961 with no~~ shows of oil, although insignificant shows of coal gas were reported.

Reservoir Characteristics

The Kuskokwim Group penetrated by the Napatuk Creek No. 1 have well log porosities of less than 12 percent; however, porosity measured from selected core chips is less than 3 percent. This is due to poor sorting of the sandstone beds that have silty matrices (graywacke) and calcite and silica filled fractures. Core descriptions from the well refer to most sandstone intervals as tight, meaning low porosity and permeability. The Kuskokwim Group within the Bethel basin area does seem to have apparent porosity in which a gas reservoir could exist, probably toward the southeast from the Napatuk Creek well location, in the basin depocenter.

The Tertiary is approximately 2,100 feet (640 m) in thickness and consists predominantly of siltstone and silty sandstone. These rocks usually make poor reservoirs due to the high clay content and lack of pore space. However, the Tertiary rocks may thicken to the southeast and have cleaner and, thus, better reservoir sands.

TABLE 2. ORGANIC GEOCHEMISTRY FROM CRETACEOUS ROCKS, YUKON DELTA NWR

LOCATION		STRATIGRAPHIC UNIT	TOC (%)	TOTAL EXTRACT (ppm)	HYDROCARBONS (ppm) (PAR + NAPH + AROM)	NONHYDROCARBONS (ppm) (ASPH + NSO CMPDS)	TAI
St. Michael	Sec. 34, T26S,R22W	Undiff Cret.	0.10	81	---------------	73 (ASPH)	2 to 2+
St. Michael	Sec. 32, T27S,R19W	Undiff Cret.	0.45	140	---------------	97 (ASPH)	3 to 3+
Marshall	Sec. 30, T22N,R83W	Undiff Cret	0.10 to 0.29	126, 316	---------------	75-260 (ASPH)	4- to 4
Kwigak	Sec. 21, T23N,R57W	Undiff Cret.	0.17	62	---------------	56 (ASPH)	
Kwigak	Sec. 29, T23N,R76W	Undiff Cret.	0.39 to 0.32	183	---------------	130 (ASPH)	2 to 2+
Nelson Island	Sec. 31, T7N,R89W	Undiff Cret.	0.19	294	45	249	2 to 4+
Nelson Island	Sec. 28, T7N,R89W	Undiff Cret.	0.08 to 0.38	79 to 242	---------------	48 to 144 (ASPH)	2 to 3-
Nunivak Island	Sec. 2, T1N,R103W	Undiff Cret.	0.54	220	---------------	181 (ASPH)	4- to 4
Nunivak Island	Sec. 5, T1N,R102W	Undiff Cret.	0.87	100	---------------	76 (ASPH)	3+ to 4
Nunivak Island	Sec. 13, T3N,R100W	Undiff Cret.	0.12 to 0.28	109 to 195	---------------	74 to 161 (ASPH)	2+ to 4-

The only known potential reservoir rocks within the Lower Yukon basin are the mid-Cretaceous clastic rocks exposed along the Yukon River. The reservoir quality of these rocks is poor because they have been considerably deformed, leaving limited sandstone porosity and permeability. Lyle and others (1984) reported sandstone porosity from selected outcrop samples to range from 1.2 to 8.1 percent effective porosity, and permeability .07 to 2.4 millidarcies (horizontal permeability). Most of the sediments are of volcanic origin and have been altered to lautmontite, which limits the porosity.

Areas of Oil and Gas Potential

The Yukon Delta and Togiak NWRs have been classified into areas of low, moderate, and no potential (plate 6) for the occurrence of oil and gas, in accordance with the BLM Mineral Classification System (appendix 2). The area identified as moderate potential is for gas only. The remaining areas are low and have no potential of oil or gas occurrences.

The areas of no potential for hydrocarbon occurrences are the areas of the Ahklun and Kilbuck Mountains of Togiak and the eastern boundary of the Yukon Delta NWRs (plate 6). These areas include the Togiak, Goodnews, Kilbuck, and Nyac Terranes. The Togiak and Nyac Terrane volcanic and volcaniclastic rocks are moderately to severely deformed and are intruded by ultramific rocks and granitic plutons. The Nyac Terrane is relatively unfoliated, but has lower greenschist metamorphic facies. The Goodnews Terrane is composed of metamorphic blocks of tuff, chert, basalt, graywacke, limestone, gabbro, and ultramific rocks, roughly in that order of abundance (Decker and others, in preparation, 1987), that have transitional blueschist-greenschist metamorphic facies (Box, 1985b). The Kilbuck Terrane is completely recrystallized metamorphic assemblages of Precambrian age. The area is also severely deformed by faulting and folding. These rocks have very little to no potential for hydrocarbon occurrences (O/D).

The Nushagak Peninsula, in the southeast area of the Togiak NWR is considered a low potential area (L/A). The Peninsula is adjacent to the Togiak Volcanic Terrane (Kulukak Subterrane) that has been described as overwhelmingly volcanogenic. These rocks are not favorable for hydrocarbon generation and accumulation. The rocks may partially extend beneath the Peninsula; or on the other hand, Cretaceous rocks equivalent to the Kuskokwim Group, exposed farther to the north in the Nushagak-Big River hill area, may also underlie the Peninsula, but these rocks are severely deformed low grade metagraywacke (Wallace, personal communication, 1987), which usually are not favorable reservoir and/or source rocks. No wells have been drilled on the Peninsula, so the underlying stratigraphy is unknown. It cannot be determined whether or not there are overlying Tertiary rocks of reservoir quality.

The area between the Kuskokwim River and the Kilbuck Mountains (plate 6) is classified as low potential for the occurrence of hydrocarbons (L/b). This area is covered by Quaternary deposits, although it lies just west of the exposed andesitic volcanic rocks and granitic intrusion of the Nyac Terrane. The area marked by the high intensity magnetic anomaly (plate 5), suggests the continuation of the volcanic deposits and/or igneous intrusions of the Nyac Terrane beneath the Quaternary deposits. This apparent continuation of Nyac Terrane follows the Kuskokwim River meander belt near the mouth of the river and extends to the northeast near the vicinity of Aniak. The Nyac Terrane rocks, as previously discussed, are not conducive for accumulation of oil or gas. Northwest of the Kuskokwim River (from Aniak) and south of the Yukon River, in the northeast corner of the Yukon Delta NWR, the Portage Mountain Sequence and Koyukuk Terrane crops out (plate 3), neither of these terranes are favorable for oil and gas, i.e., the Koyukuk Terrane is predominantly volcanic and the Portage Mountain Sequence is highly deformed and altered volcanic and sedimentary rocks. These rocks, as suggested by the magnetic anomalie (plate 5), may underlie the Quaternary deposits in this area. The Kuskokwim Group probably overlie these rocks.

The Bethel basin (plate 6) has moderate potential for gas only, as indicated by geochemical data obtained from the Napatuk Creek well. The Cretaceous rocks are thermally mature for gas, but are characteristically over mature for liquid hydrocarbons; the Tertiary rocks are thermally immature. The type kerogen for the entire well is described as gas prone type kerogen; the total organic carbon is unknown to the authors. The well was plugged and abandoned with no shows of hydrocarbons except for insignificant shows of coal gas. The area is moderate potential (M/A) because the Cretaceous rocks are fairly thick, with apparent porosity, and thermally mature for production of hydrocarbons (gas). Also, under the BLM classification system, the reported occurrence of the gas justified a moderate-potential classification.

The Lower Yukon basin, as well as the remaining Yukon Delta NWR lowland (plate 6), has a low potential (L/B) for the accumulation of hydrocarbons. The only known reservoir and source rocks for the area are the exposed, mid-Cretaceous sedimentary rocks, composed primarily of graywacke and siltstone. The type of kerogen reported from outcrop samples (table 1) are woody-coaly, gas-type kerogens that are thermally mature. The amount of organic carbon is less than 0.5 percent (table 1) which is considered the minimum threshold level for hydrocarbon source rocks (Lyle and others, 1982). The reservoir quality of these rocks is judged poor. They have been intensely deformed, leaving limited sandstone porosity and permeability.

The high magnetic intensity lineament along the westernmost margin of the basin suggests an extensive underlying intrusive body. The sediments may also become thinner in this area, thus limiting the reservoir potential, if any.

The eastern edge of the basin is marked by a magnetic basement high which appears to correlate to metamorphosed mafic volcanic or metasedimentary rocks. Oil and gas usually do not occur in these types of rocks.

The Cretaceous sediment exposed on Nelson and Nunivak Islands also have low potential for the occurrence of oil and gas. The sediments are similar in character and organic geochemistry (table 1) to those discussed above.

HYPOTHETICAL OIL AND GAS DEVELOPMENT SCENARIO

Production Scenario

As mentioned in the geological assessment, the potential for discovering economical quantities of hydrocarbons is low throughout the Togiak Refuge. However, the assessment gave a portion of the Yukon Delta Refuge a moderate potential of finding economical natural gas reserves. Due to the location of this refuge and the estimated "most likely" gas reserves, the scenario presented assumes the market for this gas will be a local village or villages near the developed field.

The following scenario was developed under these assumptions: The three- to six-inch production pipeline would be buried, there would not be a road connecting the field to existing road insfrastructure, all equipment, facilities, and supplies needed to develop and produce the gas would be transported by barge to the refuge and overland to the field during the winter months, field personnel would be transported to and from the field by small aircraft, and domestic water would be taken from local sources.

In the event of an economic discovery in the Yukon Delta NWR, development and production activities would begin on a year-round basis. Proposed plans for the production and transportation facilities are developed during the economic study of the discovery and submitted to local, State, and Federal agencies for approval. After completing the required review process, the plans are either approved or denied pending further information, studies, and/or modifications. Once approved, construction of the permanent pad, air supportfacility, and roads could begin. The first activity is to establish a temporary camp for the construction workers. As the pad and road infrastructure nears completion, the necessary wells could be drilled, the pipelines buried, and the needed production facilities and camp modules transported to the field and assembled. The modules would be designed to last the life of the field. Considering the likelihood of gas production and the potential market(s), one would expect this hypothetical field to produce for 10 to 20 years. → no it doesn't - (pg 1-14)

For illustrative purposes, figure 9 shows the location of the facilities needed to produce our hypothetical prospect. Table 3 summarizes the acreage disturbed and gravel requirements for each facility, and table 4 is a summary of total acres disturbed and gravel required to develop this prospect. The drilling/production pad used in this scenario is designed to produce the entire prospect. Depending upon actual reservoir characteristics, more pads may be required to adequately deplete the resources. Once the gas is depleted from the prospect, the wells would be plugged, the facilities removed, and the disturbed surface reclaimed per Federal and State regulations.

Prospect Boundary

Roads

Pipeline

CPF – Central Production Facility

DP – Drilling/Production Pad

Scale (miles)

0 2

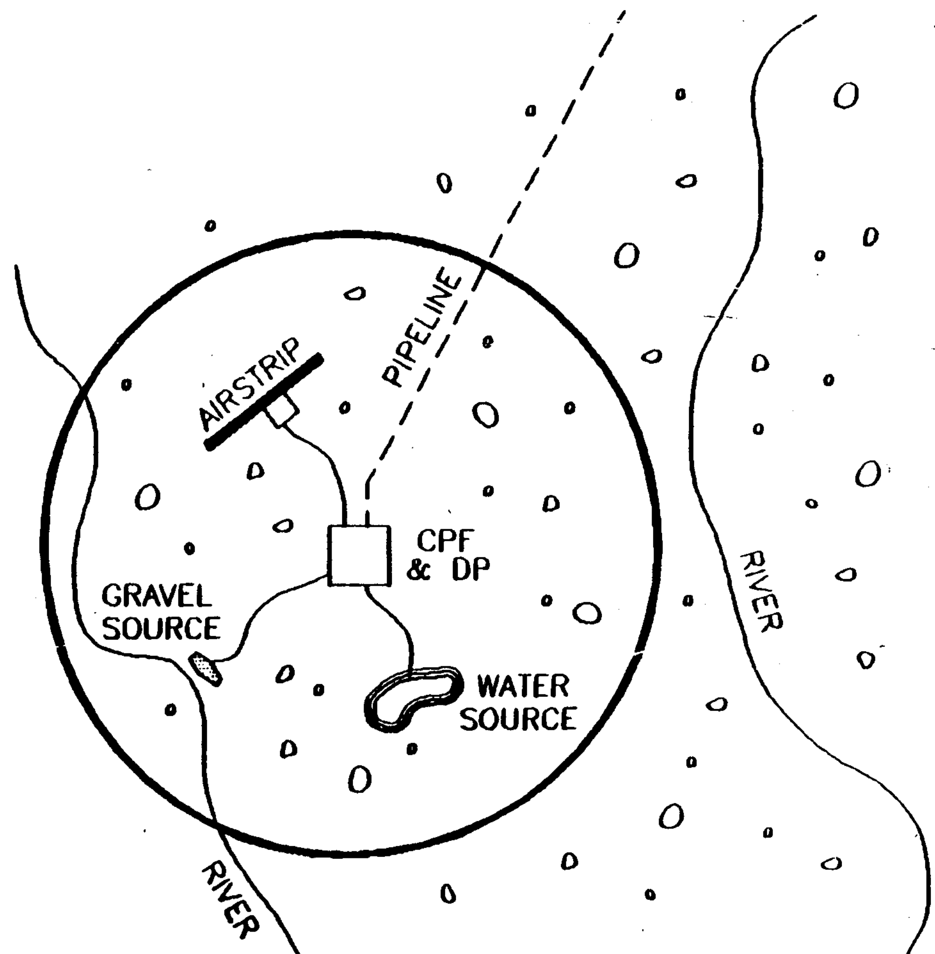


Figure 9.
Hypothetical Prospect Development Scenario

Table 3

Production Facilities
Yukon Delta NWR

Facility	Acres Disturbed (each)	Cubic Yards of Gravel to Construct (each)
Central Production Facility Pad & Drilling/Production Pad	20	100,000
Airstrip and Facilities	8-10	40,000-50,000
Roads	4 acres/mile	20,000 yd^3/mile

Table 4

TOTAL ACRES DISTURBED AND TOTAL GRAVEL REQUIREMENT FOR THE DEVELOPMENT OF THE YUKON DELTA NWR HYPOTHETICAL PROSPECT

Facility	Acres Disturbed	Cubic Yards of Gravel to Construct
Central Production Facility Pad & Drilling/Production Pad (1)	20	100,000
Airstrip and Facilities (1)	9	45,000
Roads (1.5 miles)	5	26,000
TOTALS:	34	171,000

Production Facilities

As shown, the facilities needed for the production of oil and gas are the central production facility, drilling/production pad, airstrip, pipelines, and roads.

Central Production Facility (CPF)

The CPF is the headquarters and primary operations center for the production activities of the field. Buildings on this pad would enclose the production equipment, housing needs, and office space. Areal extent of this pad is approximately 20 acres. It was assumed that this pad and the roads would be constructed very similar to those in the Kenai Wildlife Refuge. Estimated thickness of this pad is two to three feet. Before construction began, detailed studies of the area would be performed to determine the most effective and economical construction design to protect the environment. Assuming a three-foot thickness and a 20-acre pad, approximately 100,000 cubic yards of gravel would be required.

A housing module would include sleeping and eating quarters, food storage area, and recreational and sanitation facilities. The module would be designed to accommodate 2 to 5 workers. The office module and shop would provide the necessary support services to develop and produce the field.

The production module would house a separator unit, compressor unit, and a gas cooling unit. Produced gas would be dehydrated, compressed, cooled, and sent down the production pipeline. Any produced water would be disposed down an injection well.

Water for domestic use would be obtained from rivers, local lakes, or water-filled pits (abandoned gravel source areas). Insulated tanks would store a sufficient amount of potable water for human consumption. Sewage treatment facilities and the incinerator would eliminate most of the human waste and trash. Items which could not be burned would be adequately stored and transported to an approved disposal site during the winter months.

Fuel storage would hold diesel and other refined petroleum products necessary for operating the equipment of the CPF. The area would be diked to contain any spills which may occur. Electricity would be provided by a natural gas powered generation plant.

Drilling/Production Pads

A drilling rig and necessary equipment and supplies for drilling the wells would be placed on the drilling/production pad. As wells are completed, wellheads and pipelines would be put in place. The size of these pads are dependent upon the number of wells drilled and the distance between wellheads. The presented scenario shows the CPF and drilling/production pad as one. For this hypothetical prospect, a 20-acre pad would be large enough to support the CPF modules and the 6-7 wells needed to produce the field.

Depending upon the proposed depth and subsurface conditions, production wells will take 10-60 days to drill and complete. Production from each well is piped to the CPF.

Production wells are directionally drilled from the pads to various bottom hole locations within the hydrocarbon reservoir. The procedure allows maximum depletion of the reservoir and minimizes the surface acreage disturbed. Spent drilling fluids would be injected into the subsurface and the solids, if environmentally sound, would be capped in the reserve pits. If the pits cannot be secured, the material would be transported to an approved disposal site during the winter months.

Airstrip, Roads, and Pipelines

The airstrip would be permanent and maintained year-round for the lifetime of the project. It is assumed the facility would be designed for small aircraft transporting personnel to and from the field. Minimum length of the airstrip would be 2,600 feet and minimum width would be 50 feet. Three acres of surface would be covered by the airstrip itself and another 5-7 acres are required for the taxiway, apron, and support facilities. Approximately 45,000 cubic yards of gravel would be required to construct this facility.

Roads will connect all of the above facilities. They will be built with a crown width of 35 feet and would be two to three feet thick. Each mile of road would cover four acres of surface and require 20,000 cubic yards of gravel. Total mileage may vary, depending on the size and surface features of the prospects.

Gathering lines would run from each well to the CPF. These lines would most likely be buried along the most direct route. Diameter of the pipe, for this hypothetical prospect, would be two or three inches.

The main production pipeline leaving the field would probably be three to six inches in diameter. The route of the buried pipeline to market will depend on circumstances at the time production begins. This scenario assumes a nearby village would be interested in purchasing natural gas for their local needs. If an interested village is located near the gas discovery, a road connecting the village to the field infrastructure may be economically built. This would eliminate the need for housing and office modules on the CPF pad, which would decrease the size of this pad to 5-7 acres.

Economic Potential

Background

The Yukon Delta NWR (41,080 square miles) and Togiak NWR (7,350 square miles) are located in southwestern Alaska and inclue both Nelson and Nunivak Islands (plate 1). Approximately 70 percent of the Yukon Delta acreage is under Federal control, as is approximately 85 percent of the Togiak NWR. The Yukon Delta Refuge is the largest of 16 within the State of Alaska. There is no road access into either refuge. Commercial and charter air service is available to many of the communities, but light aircraft, boats, snowmobiles, and three-wheelers are the primary means of transportation.

Summary of Exploratory History

Presently, oil and gas leasing is prohibited on the refuge due to its wildlife status. Subject to site-specific compatibility with refuge purposes, oil and gas exploration inclusive of seismic activities may be allowed. There are no known oil and/or gas fields either on the refuge or in the surrounding area.

Oil companies conducted geologic investigations within the Yukon Delta Refuge in the mid-1950s and into the early 1960s. Limited geophysical exploration work was carried out in the area of Bethel in the central area of the refuge during this period. In 1961, the one and only exploratory well drilled in the Yukon Delta Refuge was completed 35 miles southwest of Bethel to a depth of 14,910 feet. This well, the Pan American Napatuk Creek No. 1, encountered some coal gas, but was plugged and abandoned in the same year as the findings were considered unfavorable. Shortly after this period in the early 1960s, interest in the Yukon Delta Refuge by the oil companies dropped sharply as indicated by the drop in exploration and leasing activities. Much of the geological and geophysical data generated by the oil companies during this period is considered proprietary and is not publicly available.

Summary of Geologic Potential

The geologic petroleum potential[1/] of the Yukon Delta and Togiak NWRs has been evaluated by this office based on available geological and geophysical information. Based on guidelines found in the BLM Manual, Section 3031 (see

[1/] Geologic petroleum potential refers only to the probability of the presence (occurrence) of a concentration of that mineral resource. It neither refers to or implies potential for extraction or that the concentration of the resource, if any, is economic or could be extracted profitably.

appendix 2), the of the refuges were determined to have either a no, low, or moderate potential for the accumulation of gas resources and either a no or low potential for oil.

No exploratory oil wells have been drilled on the Togiak Refuge, although some superficial geological investigations have been undertaken by several oil companies. Interest in the area over the years appears to have been extremely limited, and again, the results of investigations are not publicly available. Oil and gas seeps have been reported on several locations along the Yukon River bordering the Yukon Refuge, but these findings have not been confirmed by the U.S. Geological Survey, and they consider them doubtful.

As can be seen in plate 6, the only area of moderate geologic potential for the accumulation of gas is in the Bethel basin. The basis for this determination is based on visual kerogen and vitrinite reflectance data obtained from the Napatuk Creek No. 1 well. Also, the thick Cretaceous sedimentary rocks seem to have apparent porosity in which a gas reservoir could exist.

In classifying the mineral potential for lands within the subject refuges, the BLM Manual requires that a determination be made as to the reliability of the data used, based on the type and quantity of data available to make these judgmental calls. As can be seen in appendix 2, there are four categories for data quantification, known as "Levels of Certainty." These levels of certainty are 'A, B, C, and D," with "D" representing the highest level of certainty and data quantification, and "A" representing the lowest or least reliable category.

For the subject refuges, the level of certainty for all areas of low oil and gas resource potential with one exception, was determined to be "B." The southern tip of the Togiak Refuge was designated as "A" as was the one area of moderate resource potential for gas in the Bethel basin. The area determined to have no potential was classified as "D." This "no potential" area encompasses approximately 75 percent of the Togiak Refuge, as well as the southeastern corner of the Yukon Refuge.

The definition for these three levels of certainty/reliability from lowest to highest are as follows:

A. The available data are insufficient and/or cannot be considered as direct or indirect evidence to support or refute the possible existence of mineral resources within the respective area.

B. The available data provide <u>indirect</u> evidence to support or refute the possible existence of mineral resources.

C. The available data provide <u>abundant direct</u> and <u>indirect evidence</u> to support or refute the possible existence of mineral resources.

Development Potential

The development or economic potential of an area considers not only the geologic environment concerning the existence of mineral resources, but also the nongeologic environment.

The nongeologic environment includes such considerations as market availability, the existing infrastructure in the subject area, price projections, costs of production and marketing, anticipated rate of return, and also alternative investment opportunities.

The subject refuges have been determined to be in an area of "low" economic and development potential for oil and gas resources. By this is meant, that it is very unlikely that these refuges will be subjected to exploration and development within the next 25 years. There is a small, but remote possibility that there may be some interest in exploring for gas in the Bethel basin for utilization by nearby villages, but again, this prossibility is considered slim to none. As previously indicated, only one exploration well has ever been drilled in this entire area of over 48,000 square miles, and the findings from this one well, drilled in 1961, were disappointing. Since this time, and over the last quarter of a century, industry has shown very little, if any, interest in the area. This is not expected to change over the same time period in the future.

In conjunction with the above facts, the physical remoteness of the area, lack of infrastructre inclusive of the nonexistence of roads, would result in industry incurring high capital costs to explore and develop this area. The closest existing production to this refuge is in the Cook Inlet fields, approximately 280 miles east of the Togiak Refuge of in the Prudhoe Bay Field, 620 miles northeast of the Yukon Delta Refuge. It is expected that industry, in ranking this area against other investment opportunities, would be strongly inclined to focus their interest on areas showing greater promise.

Current technology exists that would allow exploration and development of potential hydrocarbon resources from this refuge, should commercial quantities be discovered; so the interest in opening this area to exploration is dictated by the resource potential and economic viability of oil and gas development in the area.

Price Projections

Current petroleum price projections compiled from a variety of sources2/ are significantly lower than previous forecasts completed earlier in the 1980s (Appendix 3, table 1). The range of oil prices projected in these current forecasts vary from $18 to $42 per barrel by the year 2000 (constant 1984/85 dollars). With such a wide spread in forecasts, it is difficult to assess

2/ U.S. Department of Energy, 1985
Data Resources Incorporated, 1986
Chevron Corporation, 1986

future impacts of this variable on future exploration activities. It was of interest to note that both a private research firm and a major oil company forecast a crude oil price of $35/barrel, whereas the most optimistic level of $42/barrel was a forecast of the U.S. Department of Energy (DOE) and was dependent on high economic growth. Assuming that high economic growth is not achieved, the DOE mid-range forecast of $36.75 is less than $2/barrel higher than those of the private sector. This level ($36.75/barrel by the year 2000) is approximately $5/barrel, or 12 percent, less than the average annual refiners' cost of imported crude in 1981/82 (constant 1984 dollars). This scenario does reflect an optimistic picture as compared to the current pricing structure.

Other forecasts from the same sources indicate an upward trend in petroleum demand, but conversely project a decline in domestic production which is indicative of a decrease in domestic exploration activities.

One last petroleum price projection that should be considered is the scenario presented by Arlon Tussing, a Seattle based energy economist. Mr. Tussing, in late 1980, against all conventional price projections, correctly forecast that international oil prices would soon collapse. In January 1984, prior to the concern of most energy forecasters, he stated that we were headed for a 10-year cycle of falling prices, and he projected that oil would soon drop within the range of $12 to $20 per barrel. To date, this forecast has been quite accurate.

Mr. Tussing's latest forecast is even more foreboding, as he expects oil prices in constant dollars to remain within a range of $10 to $20 a barrel through the rest of the century. Beyond this timeframe, he expects energy prices to decline even further.

The basis for this scenario is "fuel switching." Mr. Tussing states that "many" of the industrial users are now equipped to use alternate fuels such as oil, gas, or coal, depending on the prevailing price. He believes that the exceptional high prices during the six-year period between 1979 and 1985 were possible only because heavy industrial users were not at that time equipped to switch fuels and were heavily dependent on oil as a bulk fuel. This stemmed from the fact that exceptionally low oil prices prevailed in the 1950s and 1960s, and this trend was expected to continue ad-infinitum. He points out that for a century, between 1878 and 1978, crude oil prices never exceeded $15/barrel in 1986 dollars, and the average wellhead price during this 100-year period was between $8 and $9/barrel. Mr. Tussing believes that as long as technological progress is self-sustaining, the long-term price trend for oil can only be downward.

The wide divergence in oil price projections just presented are indicative of the future uncertainty which exists in the national petroleum industry. As we have seen, though, most mainline economists are forecasting an upward trend in long-term bulk oil prices. Although this is considered a promising sign for the industry as a whole, this is foreshadowed by forecasts of a long-term decline in U.S. production. This decline was brought on by a general cutback in drilling and production activities by U.S. petroleum companies triggered by an excess world supply and resultant low product prices. Future expansionary efforts by the petroleum industry would be anticipated to take place in areas where, hopefully, capital costs can be held down, or, in lieu of this, in areas of great promise.

Overview

In 1985, Alaska contributed nearly 20 percent of domestic petroleum production (United States Department of Energy, Energy Information Administration, 1986). In comparison, Alaska is a relatively minor producer of natural gas, with production of approximately 300 billion cubic feet per year in 1985 (United States Department of Energy, Energy Information Administration, 1986a). However, Alaska is an exporter of natural gas in the form of liquified natural gas (LNG), which is primarily shipped to Japan.

Fundamental changes in the petroleum industry since the early 1970s will certainly be a force in shaping the industry's future. This period brought two major crude oil price shocks, rapid expansion in petroleum demand and heavy reliance on foreign sources of supply to meet domestic needs. Similarly, the consumer experienced shortages in natural gas supply which resulted in a new era of gas price regulation (see Appendix 3 for a detailed discussion of these changes). The rapid growth of the energy sector in the late 1970s and early 1980s resulted in the highest petroleum prices ever experienced by the industry. This set the stage for a period of energy conservation efforts, followed by declining demand and excess world productive capacity with falling petroleum prices. By the middle of 1986, crude oil prices had dropped to levels at or below prices received in 1973, before the Arab oil embargo. Natural gas price increases stimulated drilling and production in the early 1980s, which has resulted in domestic surplus capacity (gas bubble) and depressed prices. The present unstable nature of the oil and gas industry has resulted in a great deal of restructuring within the industry and expectations for the future are very uncertain.

Most recent long-term price forecasts project an upward trend that will be realized in the 1990s and possibly beyond (see Appendix 3 for specific prices and trends). Domestic petroleum demand is expected to rise slightly above the 1985 level of 15.7 million barrels per day to a range from 15.9 to 18.1 million barrels per day by the year 2000. Natural gas demand could also increase from 17.4 trillion cubic feet per year in 1985 to a possible range from 17.1 to 20.4 trillion cubic feet per year in the year 2000. In contrast, domestic production of petroleum and natural gas is projected to decline below 1985 levels by the year 2000 (see Appendix 3 for a more detailed discussion of historic and future petroleum and natural gas demand and supply relationships). Therefore, the United States' dependency on foreign sources of hydrocarbon supplies is expected to increase above current levels. Based on these projections, there is a considerable gap between domestic consumption and production that can only be filled nationally be exploring new areas and developing any commercial discoveries that are made.

In summary, if the subject refuges were opened to oil and gas exploration and development, some benefits would accrue to the local economy through the expenditure of exploration dollars, with some small-scale benefits to the State. Economic benefits would, of course, be dependent on industry's interest in the area and investing the necessary capital for development. Presently, and at least through the next 25 years, it is not expected that industry would have much interest in the area and would be more inclined to expend their exploration dollars in areas of greater promise. Any long-term benefitsbenefits that would accrue would, of course, be dependent on locating commercial quantities of oil and gas, that could be recovered from a favorable economic viewpoint.

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APPENDIX 1

Nelson Island

Five selected sites were visited on both the north and south sides of the island (see accompanying map), and all yielded plant megafossils in varying states of preservation. In general, localities to the north of the island appear to be less deeply weathered than those to the south. Sediments seen at each of the locations show remarkable lithological and facies similarity, all representing various thicknesses and subenvironments within a high sinuosity fluvial system. Megafossil specimens and sediment samples for sedimentological and palynological assessment were recovered from each of the sites. The sandstones referred to are all of lithic graywacke composition, with a high percentage of clay matrix.

Extensive cliff exposures on the coastline between Tooksook Bay and locality 11607 show a high degree of tectonic disturbance - a combination of mega- and meso-scale open and isoclinal folding and high angle faulting. It is probable that the inferred level of tectonic shortening has repeated the sequences described here more than once.

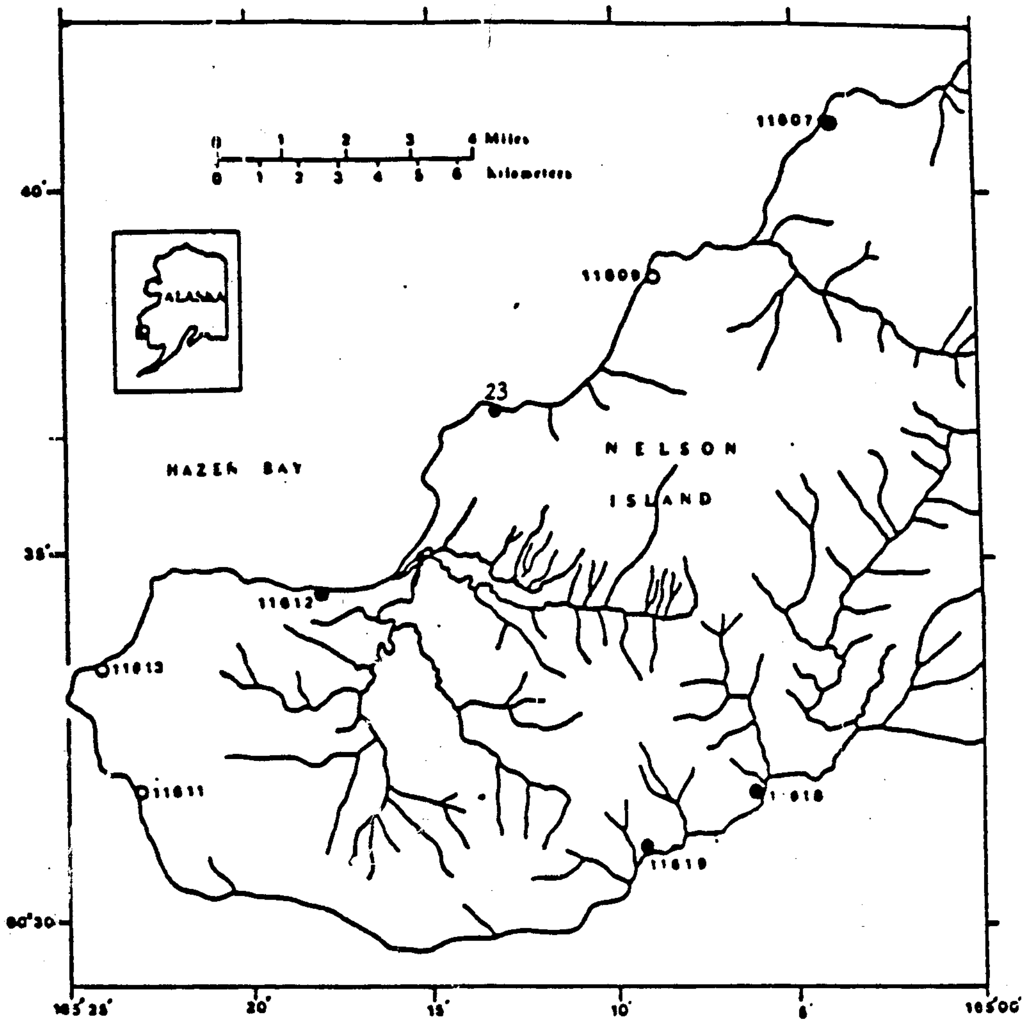
Locality 11612

The sequence represents a terrestrial fluvial system dominated by thick channel sandstones in addition to a significant development of floodplain sediments deposited in a high sinuosity regime (based on sedimentary structure within the sandstones and a relatively high proportion of fines preserved) (see figure 2). Carbonized plant debris is common throughout the sequence, particularly in float derived from the flaggy units towards the top of the channel sandstones. Degradation of organic material is high and there is some evidence of pooling by current activity. Better preservation exists near the bases of the sands where leaves were buried above the lag deposit during an initial interval of rapid deposition which led to a thickness of unstructured sandstone. Excellent preservation of fine detail on specimens exists within the overbank siltstones where leaves have been incorporated into the sediment directly after abscision. Unfortunately, plant material is so abundant that the siltstones lose their coherency and sampling is rendered difficult.

Locality 23

This sequence (figure 3) again represents part of a fluvial system. Within floodplain deposits, there is a reduced coarse clastic input and a higher concentration of organic matter, allowing the accumulation of thin coals and coaly siltstones.

FIG 1 LOCATION MAP NELSON ISLAND



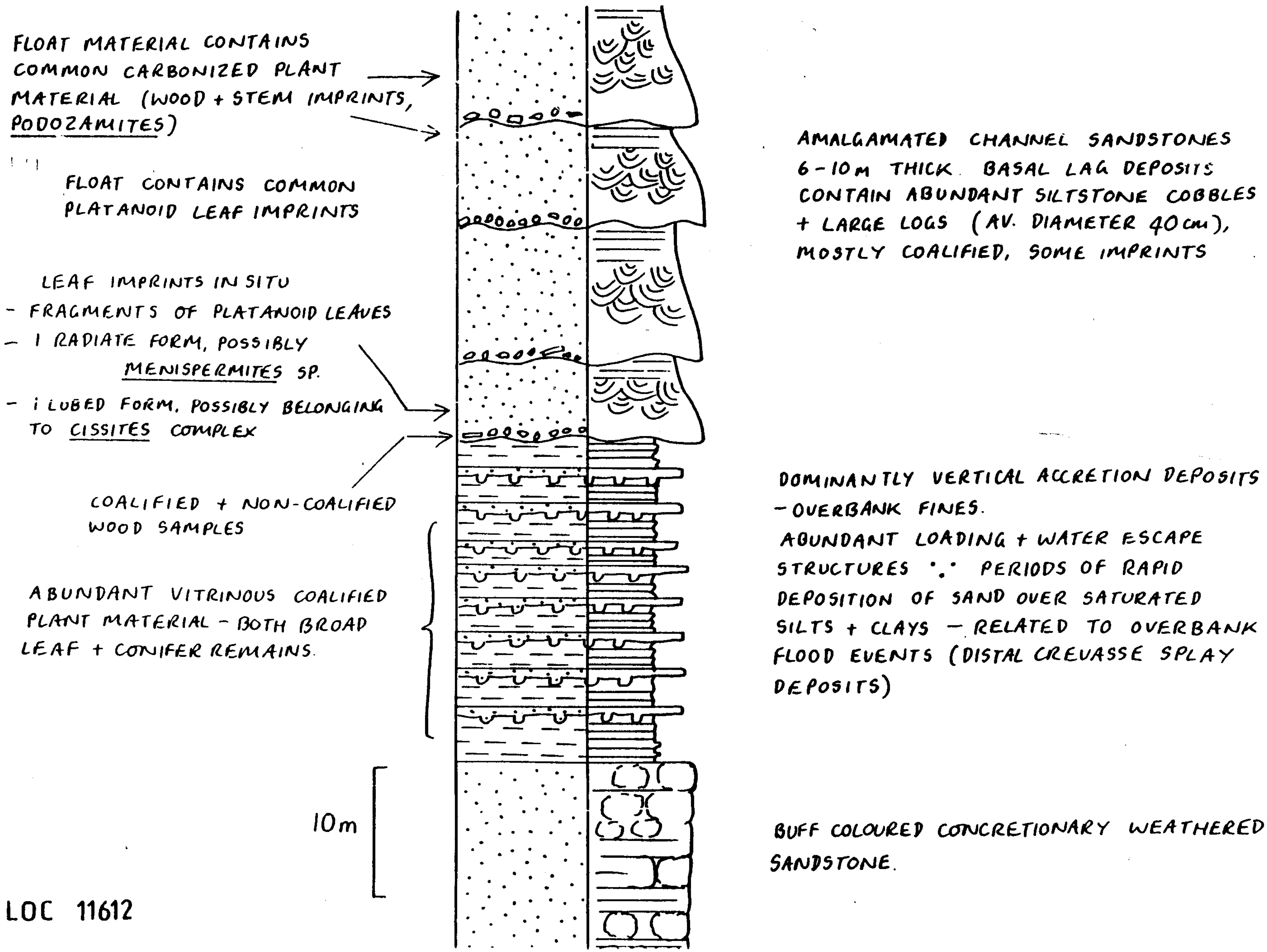


FIG 2 LOC 11612

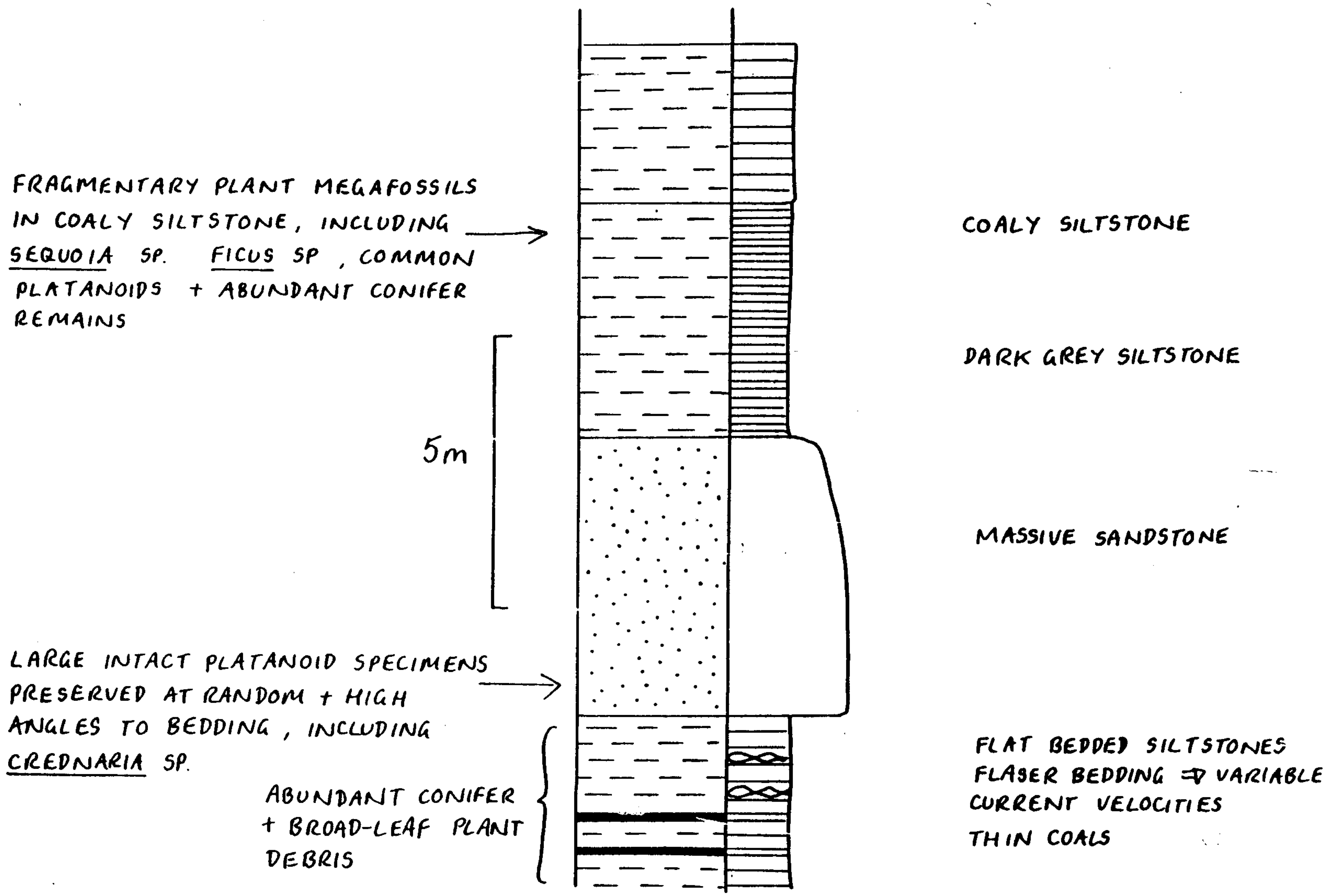

FRAGMENTARY PLANT MEGAFOSSILS IN COALY SILTSTONE, INCLUDING SEQUOIA SP. FICUS SP, COMMON PLATANOIDS + ABUNDANT CONIFER REMAINS
5m
LARGE INTACT PLATANOID SPECIMENS PRESERVED AT RANDOM + HIGH ANGLES TO BEDDING, INCLUDING CREDNARIA SP.
ABUNDANT CONIFER + BROAD-LEAF PLANT DEBRIS
COALY SILTSTONE
DARK GREY SILTSTONE
MASSIVE SANDSTONE
FLAT BEDDED SILTSTONES
FLASER BEDDING ⇒ VARIABLE CURRENT VELOCITIES
THIN COALS

FIG 3 LOC 23

Locality 11607

The energy regime within this section (figure 4) is comparable to that of section 11612 with amalgamated channel sandstones showing erosive bases and thin crevasse splay sandstones forming an integral part of overbank sedimentation.

Locality 11618 West of Tooksook Bay

The lithological section is dominated by strongly weathered siltstone and carbonaceous shale, although units of fine- to medium-grained trough cross-stratified sandstones of the order of 5 m thick are also developed. The sandstones reveal abundant coalified, partially coalified, and occasionally charcoalified plant stems up to 15 cm in diameter, occurring both within the coarse basal lags and scattered throughout the units. Also recovered were several well preserved leaf specimens of platanoid type, including Crednaria sp.

Locality 11619

The lithofacies of this locality are very similar to those of locality 11618. In addition, thin coal and bentonite horizons occur within the fine-grained units. Fragments of Podozamites and conifer shoots are abundant in the claystone and siltstone units. Broad-leaf remains (of entire and nonentire margin species) may be locally common, and one ginkgo specimen was also found.

St. Marys Area

A series of bluff exposures was studied along the Yukon River between the mouth of the Andreafsky River and Mountain Village (see accompanying map), in addition to several elevated ridge outcrops and quarry exposures located north of the river. A range of environments from terrestrial fluvial systems to inferred delta slope were studied and the representative sediments sampled, as previously noted. Two sites up the east fork of the Andreafsky River were also described, one of which yielded a number of plant megafossils. Again, sandstones are of graywacke composition. Paleocurrent measurements taken at several outcrops seem to indicate a roughly southward dipping paleoslope, although the validity of reconstruction in such deformed rocks is questionable.

The localities along the Yukon section are described, in turn, from west to east, with brief environmental interpretations, followed by a postulated structural cross-section and a discussion of its implications.

Locality 15

Small outcrops exist along a minor ridge on the east flank of the larger feature known locally as Third Gravel (see below). The exposed lithology comprises cm to dm bedded fine-grained, mid-gray graywacke showing rippled surfaces and faint cross-stratification.

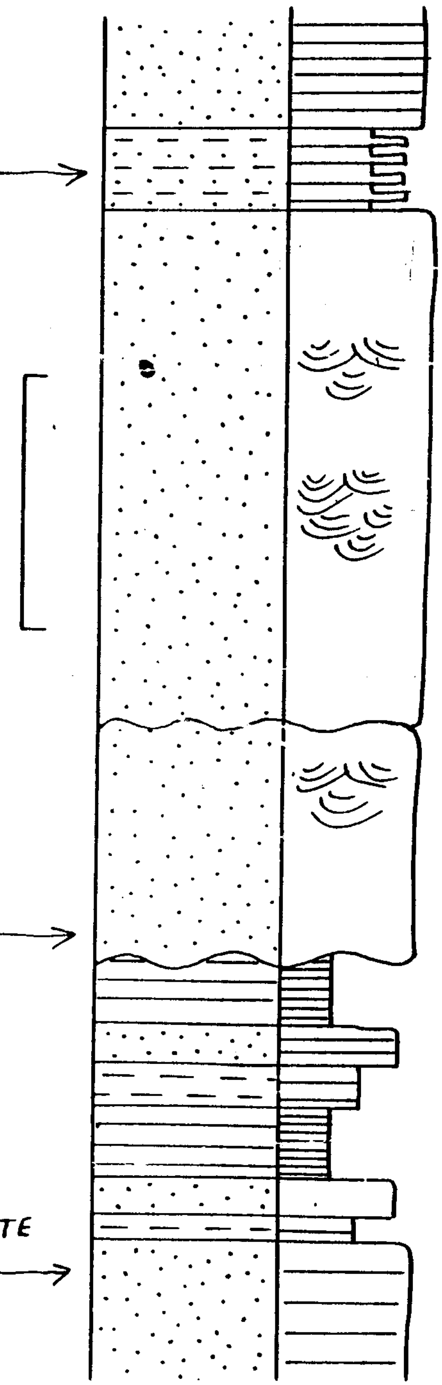


FIG 4 LOC 11607

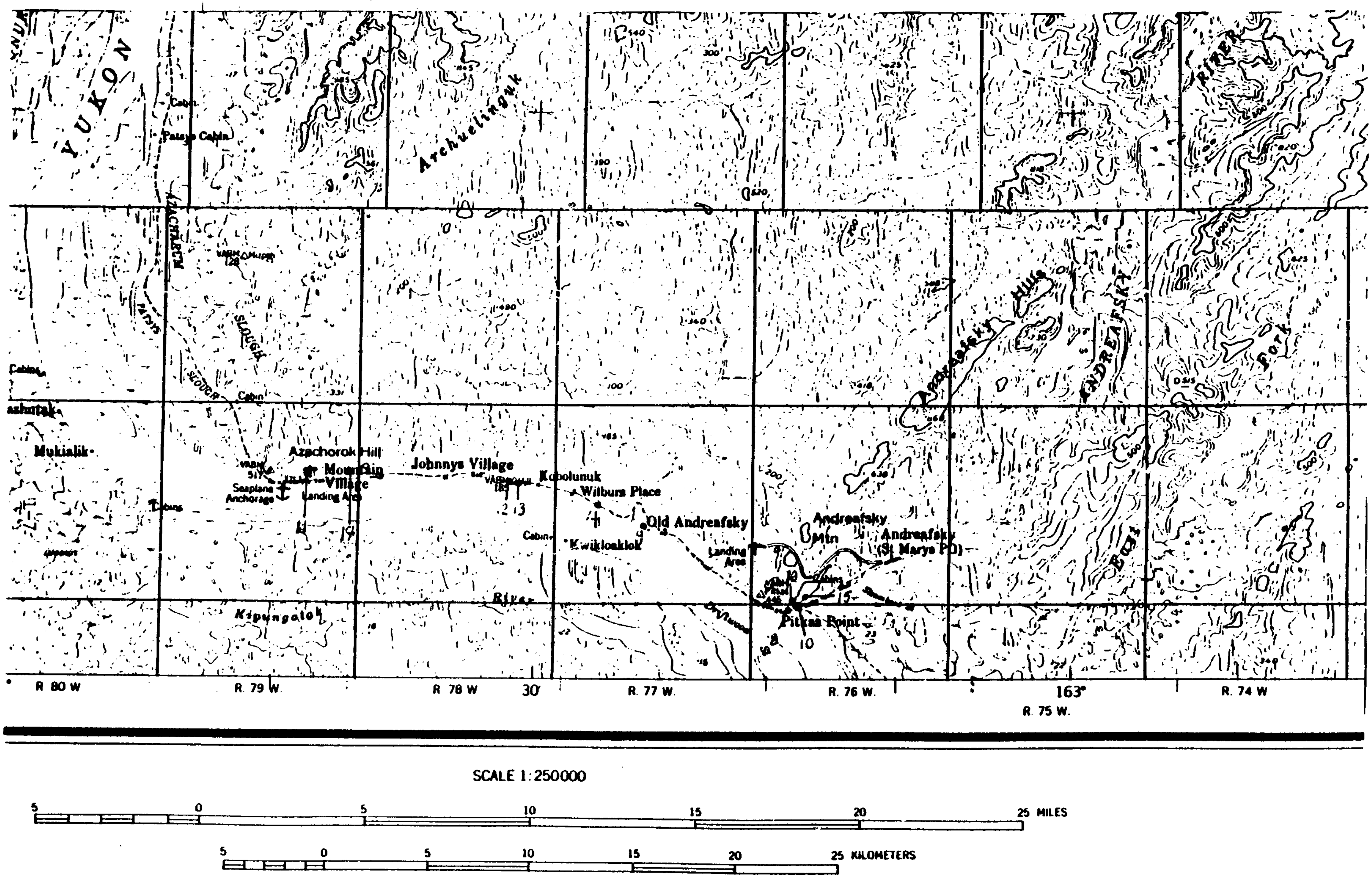

YUKON
Patsys Cabin
Cabin
Archuelinguk
AZACHARUM
SLOUGH
Cabin
Mukialik
Azachorok Hill
Mountain Village
Seaplane Anchorage
Landing Area
Johnnys Village
Kobolunuk
Wilburs Place
Old Andreafsky
Kwikloaklok
Cabin
Kipungalok
River
Andreafsky Mtn
Andreafsky (St Marys PO)
Landing Area
Pitkas Point
Andreafsky Hills
ANDREAFSKY
East
Fork
RIVER
R 80 W
R. 79 W.
R 78 W
30'
R. 77 W.
R. 76 W.
163°
R. 75 W.
R. 74 W
SCALE 1:250000
25 MILES
25 KILOMETERS

FIG 5

Locality 16

This site is located on the most westerly of the three strike-parallel ridges comprising the southernmost extension of the Andreafsky Hills. Locality 16 forms the highest point of the outcrop which continues south down to the quarry (Locality 8) on the north bank of the Yukon. The dominant lithofacies is a thin-bedded medium bioturbated, coarse mid-gray siltstone. Both small diameter (1.5 cm) vertical burrows and crawling traces are present.

Just south of the road bend on Third Gravel, a section of thin-bedded (cm to dm) graywacke sandstone is exposed and shows rippled surfaces, horizons of clay rip-up clasts, clay shale partings, and one example of small-scale Paleodictyon, indicating shallow marine conditions.

Locality 8 Pitkas Point

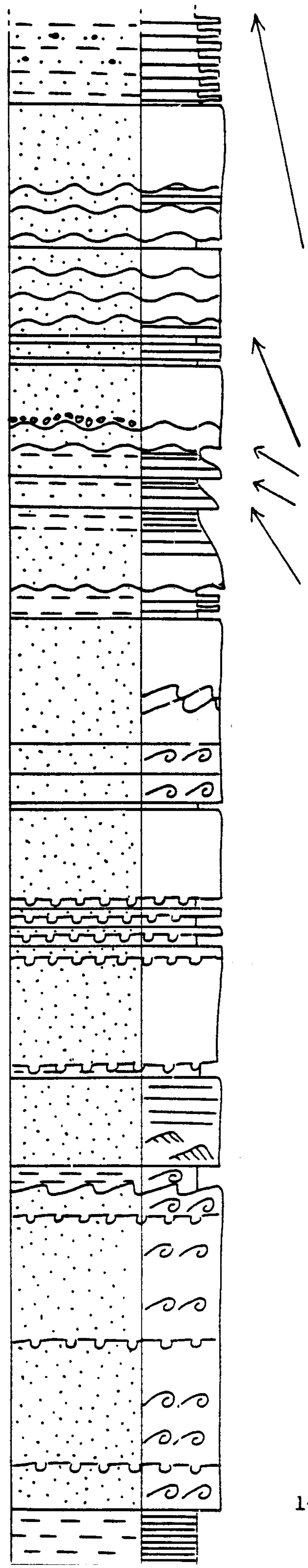
Two sections are exposed here within a short distance of each other, but appear to be environmentally unrelated. The baked nature of the quarry siltstones and quartz veining within them (not seen elsewhere) would support the existence of a structural discontinuity in the vicinity.

i. Indurated siltstone forms the dominant lithology of the quarry in which it is exposed. The siltstone shows mm scale, flat compositional, and grain size lamination which could be a rhythmic seasonal feature. Crawling traces and bioturbated horizons are abundant, and small-scale mudflow structures are also apparent. A strong iron oxide weathered horizon (seatearth?) is associated with a coal several cm thick. These features indicate slow deposition in a terrestrial environment, probably paludal.

ii. A sedimentological summary of the shoreline section is given in figure 6. The basal two-thirds of the sequence is dominated by slightly calcareous sandstones, showing common slump structures and loading features, flute casts, and some ripple cross-lamination. The overlying third of the section shows multiple erosion surfaces with lag deposits and fining-up units on a meter scale in addition to intervals of ripple cross-laminated, interbedded sandstone and siltstone.

Environmentally, this progression is taken to represent rapid mouth bar deposition from a prograding delta distributary channel, with the base of section siltstones forming the top of the delta front/delta slope. In this scenario, the upper deposits would represent sedimentation within the channel itself, capped by ripple cross-laminated, waning flow deposits following abandonment.

FIG 6
LOC 8



INTERBEDDED VERY FINE-GRAINED GREENISH/GREY SANDSTONE, CONTAINING CLAY PEBBLES, + MM LAMINATED SILTSTONE. SOME BEDDING PLANES HIGHLY MICACEOUS

DISTRIBUTARY CHANNEL DEPOSITS

FINING-UP SEQUENCES
THIN BEDDED SANDSTONE → MM LAMINATED SILTSTONE

IN PHASE CLIMBING RIPPLE LAMINATION

GENTLE SLUMP STRUCTURES

RAPID MOUTH BAR DEPOSITION

MASSIVE SANDSTONE. EROSIVE BASE WITH LARGE SCALE LOAD STRUCTURES + SMALL SCALE FLUTE CASTS

SLIGHTLY CALCAREOUS SANDSTONE

ABUNDANT SOFT SEDIMENT DEFORMATION

5m

ABUNDANT SLUMP + LOAD BALL STRUCTURES

1-9 FLAT LAMINATED SILTSTONE WITH SANDSTONE LENSES + LAMINAE

Locality 10

Poor exposure at this site consists of interbedded bioturbated silty shale units up to 6 m thick and fine-grained sandstone units containing horizons of clay rip-up clasts several meters thick. The nonbioturbated sandstone is a flaggy micaceous type, suggesting sorting by wave action. A number of bivalve fossils including Trigonia sp. were found. The section probably, at least partially, represents beach deposition.

Locality 22

A thick sequence of sandstones, siltstones, and clay shale is exposed in this quarry. For descriptive purposes, the outcrop is divided into two section since, although they show the same bedding attitude, there is no continuous exposure.

i. The lower part of the stratigraphically oldest section is summarized in figure 7. Overlying this is a similar interval if interbedded sandstones, varying in thickness from several dm to .75 m, and silty shales. Many sandstone beds exhibit sole marks in the form of flute and groove casts, while other bed contacts are essentially planar. The sandstones occasionally are thin-bedded at the top of the unit and may become interbedded with siltstone on a cm scale. However, the bed contacts will still show fluting. The silty shales tend to have a fairly uniform thickness -- around 10 to 15 cm maximum.

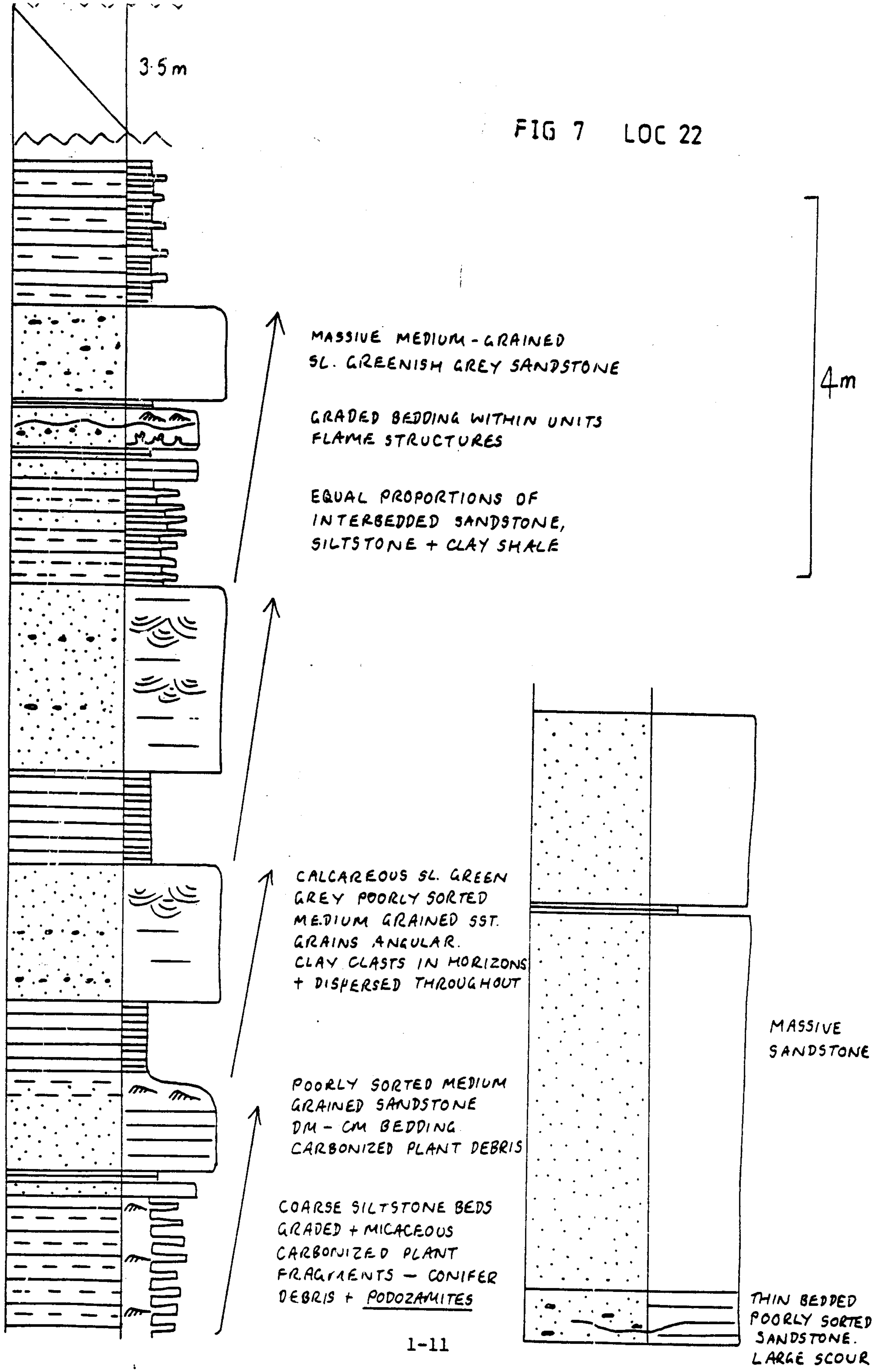
The sandstones are slightly greenish-gray, medium- to fine-grained, and poorly sorted. Generally, they appear massive, but may show faint cross-stratification, ripple cross-lamination, or planar bedding. Clay pebbles tend to be concentrated in horizons. An individual sandstone bed may show more than one interval of gradings, and occasionally, reverse grading is seen at the base of a bed. Flame structures were also observed in a sandstone unit where slightly darker, finer-grained sandstone had been injected into the overlying coarser material on liquification.

The whole section shows evidence supporting the existence of coarsening-up sequences on the basis of increasing frequency and thickness of sandstone beds. This pattern is seen on the scale of 2 to 3 m, and may be repeated within a larger scale unit, around 10 or more meters thick.

Poor sorting, graded bedding, flame structures related to loading, and the locally pervasive presence of flute casts are taken as indications of high energy and rapid deposition from turbidity currents, with reverse grading resulting from high concentrated flows; and waning flow conditions giving rise to cross-stratification of varying scales.

ii. The southerly outcrop exhibits similar coarsening-up patterns in bed frequency and thickness, although they are not as well developed. In thin

FIG 7 LOC 22


3·5 m
4m
MASSIVE MEDIUM-GRAINED SL. GREENISH GREY SANDSTONE
GRADED BEDDING WITHIN UNITS FLAME STRUCTURES
EQUAL PROPORTIONS OF INTERBEDDED SANDSTONE, SILTSTONE + CLAY SHALE
CALCAREOUS SL. GREEN GREY POORLY SORTED MEDIUM GRAINED SST. GRAINS ANGULAR. CLAY CLASTS IN HORIZONS + DISPERSED THROUGHOUT
POORLY SORTED MEDIUM GRAINED SANDSTONE DM - CM BEDDING CARBONIZED PLANT DEBRIS
COARSE SILTSTONE BEDS GRADED + MICACEOUS CARBONIZED PLANT FRAGMENTS - CONIFER DEBRIS + PODOZAMITES
MASSIVE SANDSTONE
THIN BEDDED POORLY SORTED SANDSTONE. LARGE SCOUR

bedded intervals, incomplete Bouma sequences (Ta-c(d)) are present in sandstone beds of up to 20 cm thickness (see figure 8). Tb is the dominant microfacies within these beds. Highly fragmentary plant material and occasional stem imprints are locally abundant on bedding planes.

The sediments of locality 22 are believed to be delta slope in origin, arising from rapid delta progradation. The ichnofacies is not indicative of a deep-water setting for the turbidite type deposits.

Locality 14

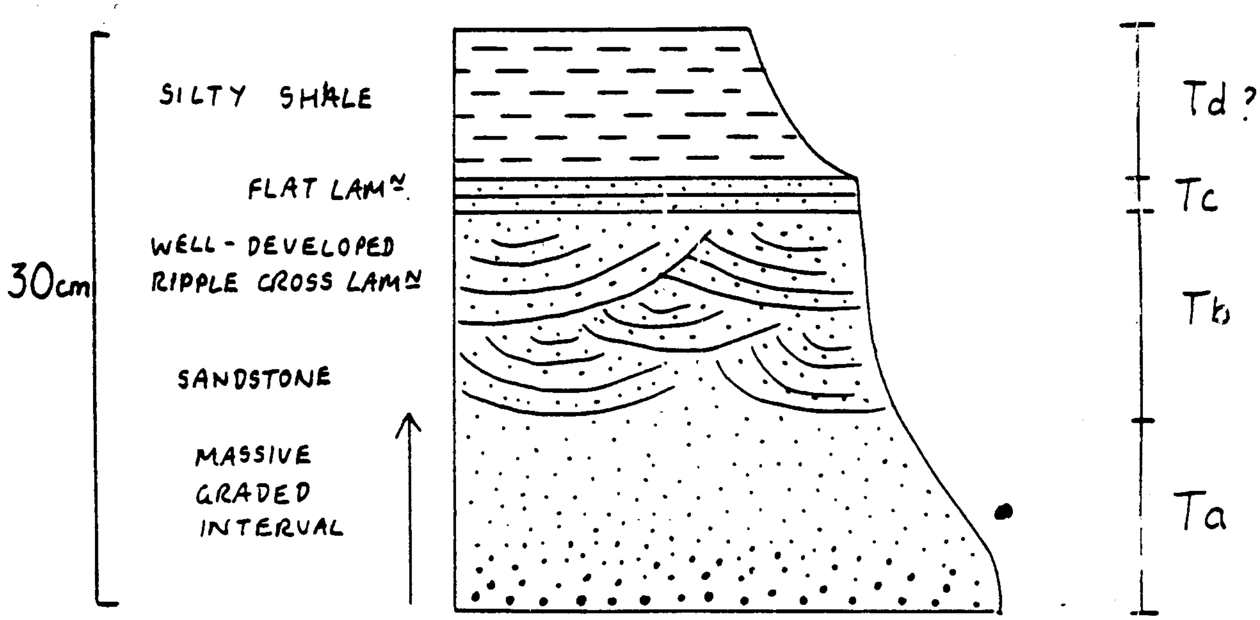
Locality 14 shows the majority of the features typical of the laumontitized division of Hoare and Condon (1984), as exposed in the bluffs between Old Andreafsky and Mountain Village, and is therefore described in detail (see figure 9).

Exposed here is an extended sequence dominated by fine-grained sandstones with abundant laumontite zeolites and siltstones containing ash grains, claystones, contorted debris flow-type deposits; lenses of coarse-grained (epiclastic) lithic sandstones are also represented.

The lower 70 m of the section is dominated by fining-up, fine-grained sandstone units, often with erosive bases and/or amalgamation surfaces up to 4 m thick. Parts of the units, particularly the bases, appear to be massive; while flat bedding, planar, and trough cross-stratification appear to be equally represented throughout the remainder of the units. Coarse lag deposits and sandstone bases are composed of claystone cobbles up to 20 cm in length, and showing random orientation. Ripple cross-lamination and locally clay flasers may be common at the top of sandstone beds. The sandstones have a high proportion of clay matrix, and coarse-tail grading within individual beds is a common feature. Claystone is often preserved in lenses where sandstone beds have become amalgamated. The overlying sandstone may exhibit large-scale loading into these lenses. Laumontite alteration often follows foreset lamination, related to sandstone composition. Sole markings include groove casts, flute casts, load casts, and intermediate (directed load cast) structures.

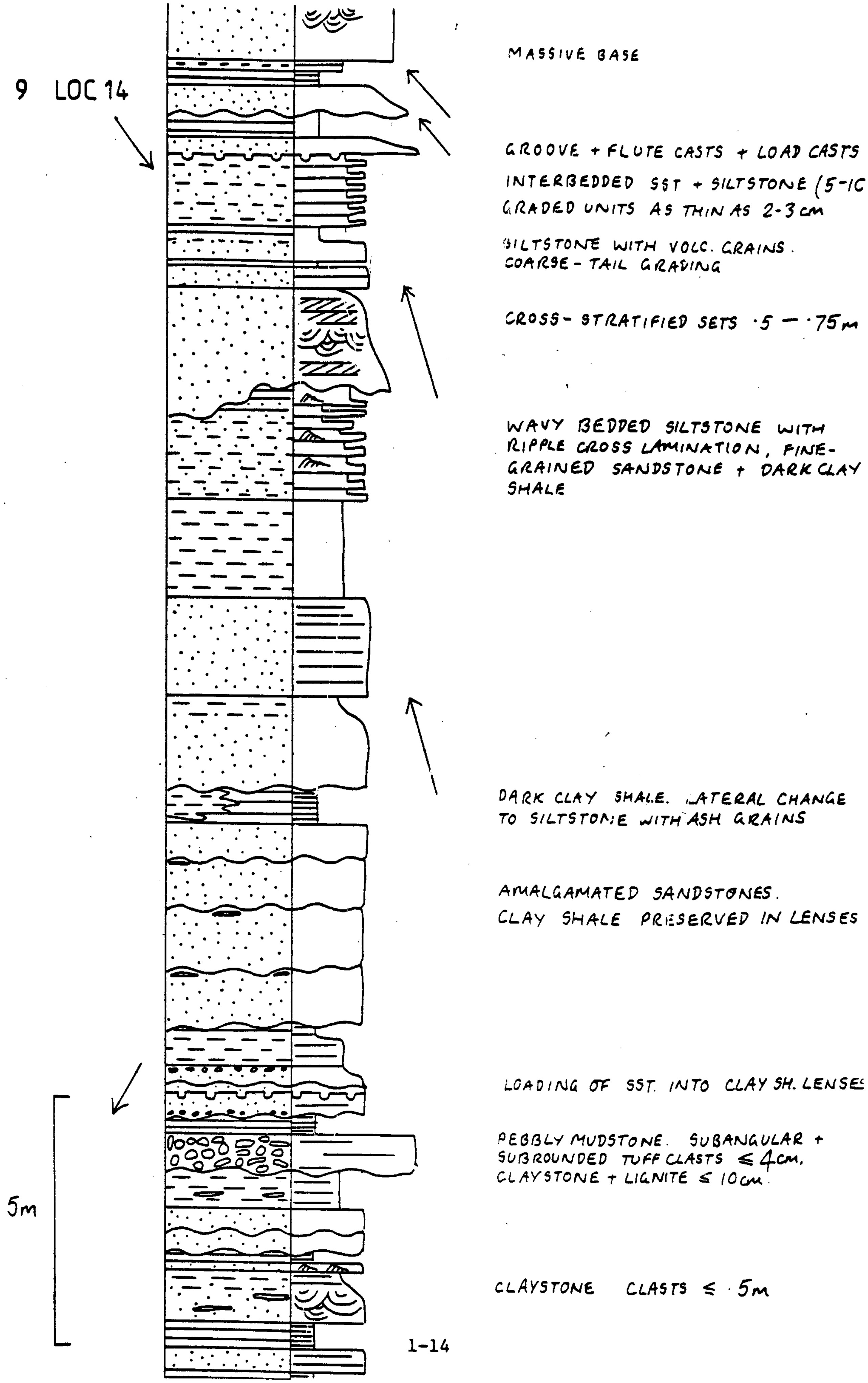
Upward gradation from sandstone to siltstone and, occasionally, claystone is often complete, but there may be an abrupt discontinuity in grain size distribution. Generally, the siltstones contain a varying percentage (up to 5 percent) of white, opaque "floating" grains. These are interpreted to be fragments of tuff, eroded from deposits upstream, and behaving hydrodynamically as silt-grade particles on account of their low density. Siltstone beds often show coarse-tail grading with respect to these grains. Graded sandstone and siltstone beds may be as thin as 2 cm, and tend to be of uniform thickness and laterally continuous. Lenses of dark claystone and intervals of interbedded siltstone and claystone reflect varying current velocities. Claystone and clay shale contain only rare pyroclastic grains.

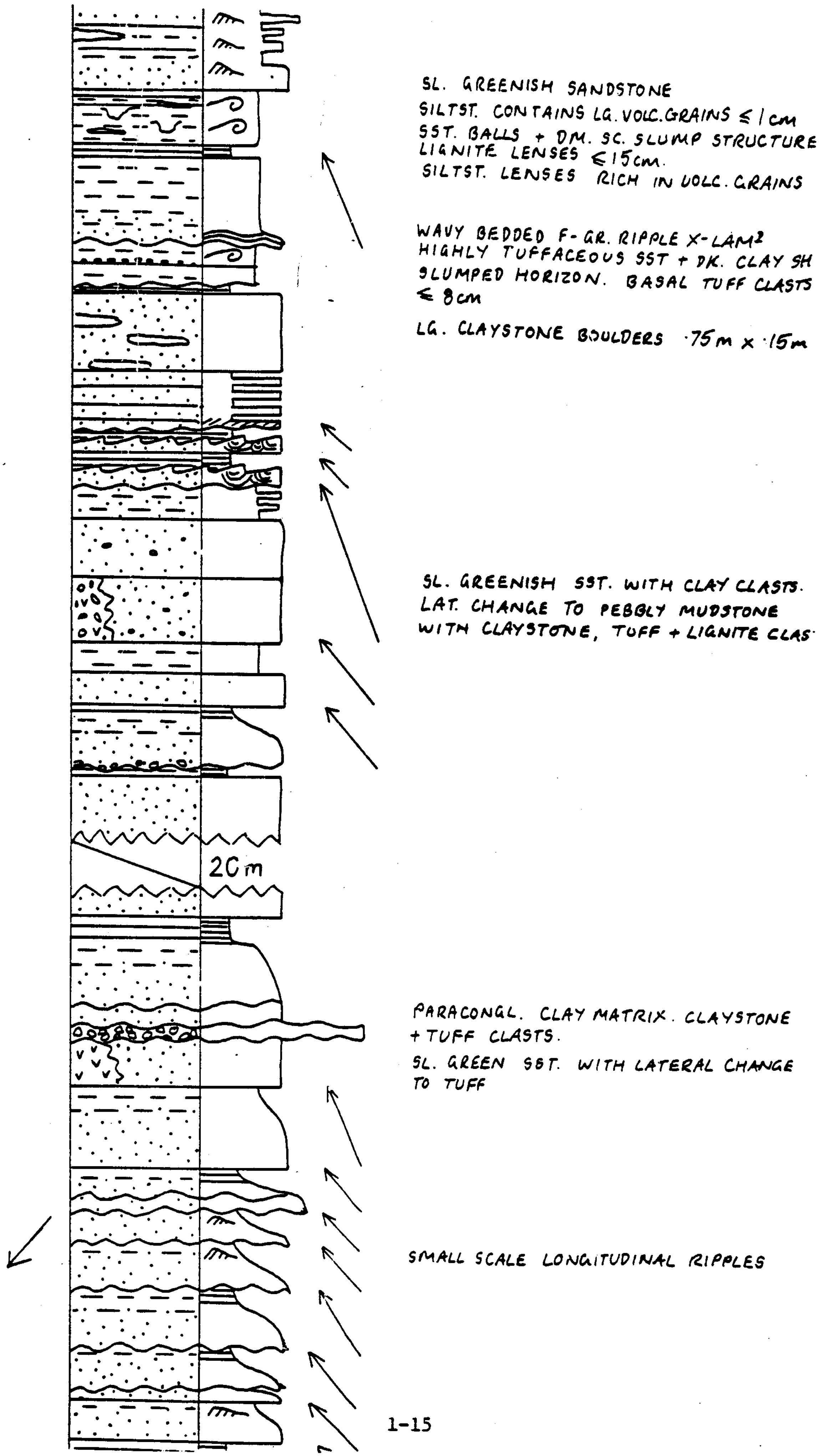
FIG 8

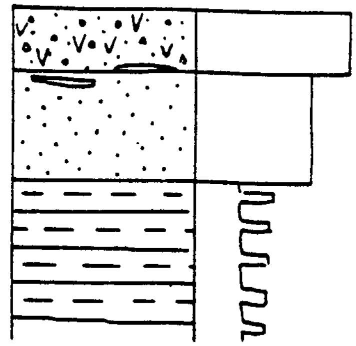


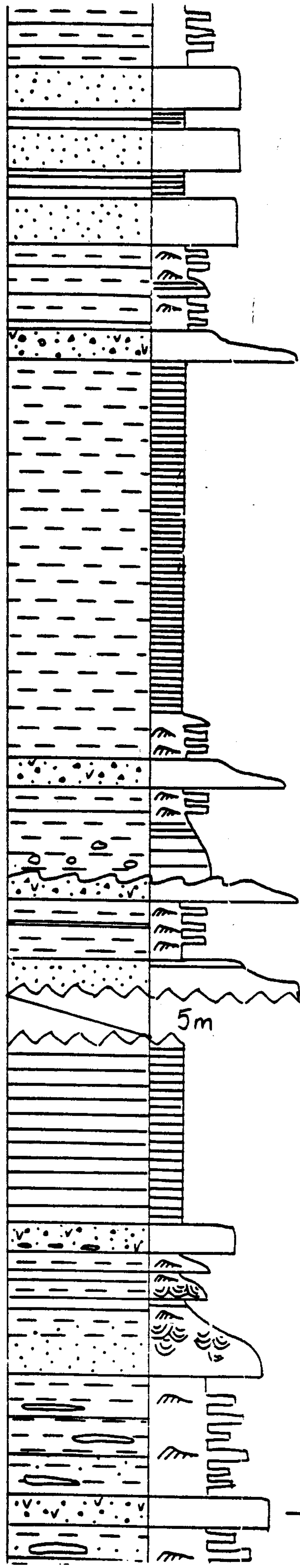
30cm
SILTY SHALE
FLAT LAMN.
WELL-DEVELOPED
RIPPLE CROSS LAMN
SANDSTONE
MASSIVE
GRADED
INTERVAL
Td ?
Tc
Tb
Ta

FIG 9 LOC 14


MASSIVE BASE
GROOVE + FLUTE CASTS + LOAD CASTS
INTERBEDDED SST + SILTSTONE (5-10
GRADED UNITS AS THIN AS 2-3 cm
SILTSTONE WITH VOLC. GRAINS.
COARSE - TAIL GRADING
CROSS - STRATIFIED SETS ·5 — ·75m
WAVY BEDDED SILTSTONE WITH RIPPLE CROSS LAMINATION, FINE-GRAINED SANDSTONE + DARK CLAY SHALE
DARK CLAY SHALE. LATERAL CHANGE TO SILTSTONE WITH ASH GRAINS
AMALGAMATED SANDSTONES.
CLAY SHALE PRESERVED IN LENSES
LOADING OF SST. INTO CLAY SH. LENSES
PEBBLY MUDSTONE. SUBANGULAR + SUBROUNDED TUFF CLASTS ≤ 4cm. CLAYSTONE + LIGNITE ≤ 10cm.
CLAYSTONE CLASTS ≤ ·5m
5m


SL. GREENISH SANDSTONE
SILTST. CONTAINS LG. VOLC. GRAINS ≤ 1 cm
SST. BALLS + DM. SC. SLUMP STRUCTURE
LIGNITE LENSES ≤ 15cm.
SILTST. LENSES RICH IN VOLC. GRAINS
WAVY BEDDED F-GR. RIPPLE X-LAM^{2}
HIGHLY TUFFACEOUS SST + DK. CLAY SH
SLUMPED HORIZON. BASAL TUFF CLASTS ≤ 8cm
LG. CLAYSTONE BOULDERS ·75m x ·15m
SL. GREENISH SST. WITH CLAY CLASTS.
LAT. CHANGE TO PEBBLY MUDSTONE
WITH CLAYSTONE, TUFF + LIGNITE CLAS
20m
PARACONGL. CLAY MATRIX. CLAYSTONE + TUFF CLASTS.
SL. GREEN SST. WITH LATERAL CHANGE TO TUFF
SMALL SCALE LONGITUDINAL RIPPLES


SLIGHTLY GREENISH
COARSE TUFF
CLAY SH. PRESER
INLENSES


70% CLAY SH (+ SILTSTONE)
LG. CLASTS OF RIPPLE X-LAM'D F-GR SS
PEBBLY SST. AS BELOW
COARSE - TAIL GRADED SANDSTONE
5m
DOMINANTLY CLAY SHALE
25% SILTSTONE BEDS ≤ 6cm WITH NO
VOLC. GRAINS
PEBBLY SST, AS BELOW
CLAYSTONE RIP-UP CLASTS ≤ 7cm
PEBBLY SST. F- MED GR BUFF SAND
MATRIX. CRS. SAND + GRAVEL GRADE
LITHIC + TUFF CLASTS.
1-16 INTERBEDDED + INTERFINGERING SILTST. +
CLAYST. + LENSES OF BUFF-COLOURED

This part of the section is believed to represent a system of short-lived, low sinuosity braided channel deposits. This interpretation is based on the high ratio of channel to vertical accretion deposits and the thickness of the channels (approximately 1 m, average), which may reflect rapid channel switching or a truly ephemeral regime. Contemporaneous volcanism is indicated by a single bentonite horizon preserved in a fine-grained interval and by a partially eroded tuff, leaching from which has given the adjacent sandstone a slight green coloration.

With the sandstones being predominantly fine-grained, coarse material exists only as claystone clasts in channel lags; and as claystone, tuff and lignite clasts in the chaotic flow deposits. It appears that the only mechanism for the preservation of partially consolidated material (ash and peat) eroded from the channel walls was within a fluidized flow. The result was an instantaneously formed, very poorly sorted, homogenous pebbly claystone. Much of the matrix appears to be derived from degraded ash material which is reflected in its very pale color. That these flows or fluidized bottom sediments, incorporating transient channel floor debris, were local occurrences is suggested by their thickness (.2 to .7 m). Under normal river flow conditions, this clast material would be rapidly abraded and dispersed. The triggering mechanism can be readily explained in a depositional setting adjacent to a region of active volcanism.

The upper 40 m of section shows a change in character to dominantly fine-grained and interfingering deposits composed of cm scale interbedded siltstone and clay shale. Ripple cross-laminated sandstone beds are also common, in addition to thin bentonites, slumped horizons, which may relate to seismic activity (volcanic events), and lenses of reworked lapilli ash containing rare glass shards. Thin channel units (around 5 m) of sandstone or siltstone showing a fining of sedimentary structure from trough cross-stratification through ripple cross-lamination to planar lamination are also present. Most conspicuous is the introduction of beds approximately 5 m thick of fine- to medium-grained buff colored, poorly sorted lithic tuffaceous sandstones which may also contain clay pebbles. These probably represent the redeposition of lapilli ash immediately following explosive volcanism. Contemporaneous volcanism is evidenced by a number of thin bentonites.

The section shows an overall decrease in modal grain size and energy conditions, probably related to a low rate of basin subsidence. The predominance of fine-grained sandstone could be due to a combination of distance from the source and source rock character.

It is interesting to note the absence of macroscopic plant remains. This may be due to the ground water chemistry involved at all stages of deposition, and diagenesis due to leaching of abundant volcanic material.

Location 9

Lithologically, this sequence is very similar to location 14. Siltstones include thin beds and lenses of highly calcareous silt which show cross-lamination, slump structures, and contain claystone pebbles. Generally, fining-up units are .5 to .75 m thick as seen at locality 14. Also present here are concentrations of small carbonized plant fragments preserved within dark gray clay shale.

Locality 13

The section observed here is similar to the upper part of section 14, with a high proportion of fines. Sandstone units are again .5 to .75 m thick, some of which contain abundant subangular volcanic grains up to 6 mm in diameter and showing coarse-tail grading. A unit 4 m thick towards the top of the section exhibits some synsedimentary folding on cm to dm scale, slumping and chaotic flow lenses on a dm to m scale which include stem imprints several mm wide.

Locality 12

This section differs slightly from the others. Planar bedding contacts, uniform bed thickness, and rhythmic nature of the sedimentation are most notable. The sequence comprises fine-grained sandstone beds .5 to 2 m thick with basal flute and groove casts and faint cross-stratification. Very fine-grained siltstone partings up to 40 cm thick are generally present, and are also cross-laminated. Occasionally, there is complete, though rapid, gradation from sandstone to siltstone. No tuffaceous siltstones are present.

Locality 17

There is a small quarry exposure just north of the Yukon. A thick meter scale trough cross-stratified sandstone shows grading and flame structures 15 to 20 cm in height. It is overlain by siltstone and clay shale.

Andreafsky River Localities

Locality 20

The limited thickness of sediment exposed here (figure 10) comprises the top of a fining-up progression from channel sandstone to overbank siltstones and claystones. The majority of the plant megafossils were recovered from the sandstone unit and are mostly of platanoid affinity. Relatively complete specimens include *Platanus newberryana*, *Pseudoprotophyllum* sp. and one entire margin form. Fragmentary plant material, including *Podozamites* and conifer shoots, is common in clay-rich horizons within the siltstones.

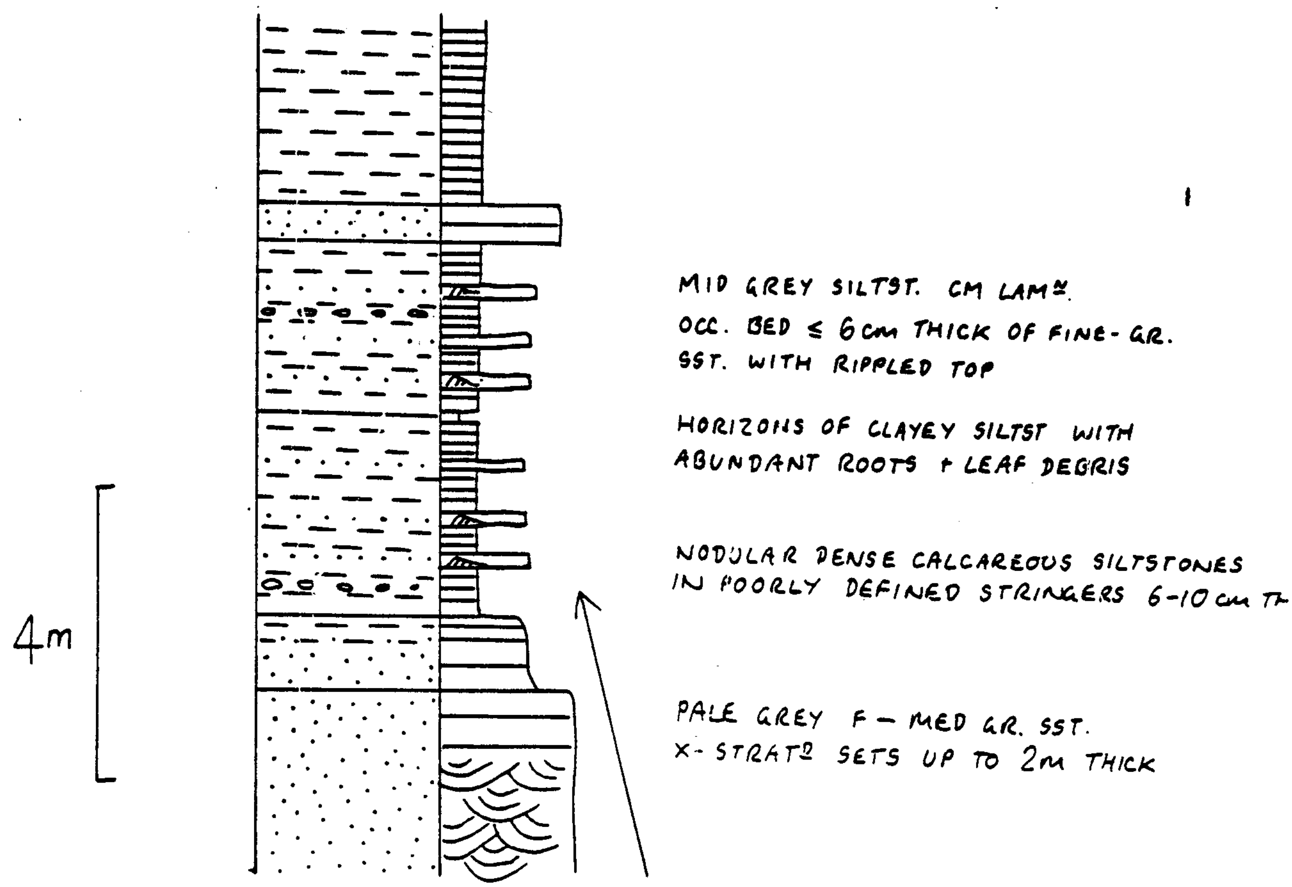

4m
MID GREY SILTST. CM LAM^{N}.
OCC. BED ≤ 6cm THICK OF FINE-GR.
SST. WITH RIPPLED TOP
HORIZONS OF CLAYEY SILTST WITH
ABUNDANT ROOTS + LEAF DEBRIS
NODULAR DENSE CALCAREOUS SILTSTONES
IN POORLY DEFINED STRINGERS 6-10cm TH
PALE GREY F – MED GR. SST.
X-STRAT^{N} SETS UP TO 2m THICK

FIG 10 LOC 20

Locality 21

This site consists of an outcrop of fairly uniform siltstone which has locally undergone strong bioturbation. Planar lamination exists within pale gray, clay-rich intervals. Several bivalves, some in life position, were recovered from bioturbated units.

Structure

When the isoclinal folds are drawn as shown (see figure 11), with outcrop constraint along the Yukon, two major northeast-plunging anticlines, overturned to the southeast, are expressed within the laumontitized division and are in accordance with the outcrop pattern seen further to the north (geological map, Hoare and Condon, 1964).

It appears from this structural interpretation that the laumontitized division underlies the calcareous division and, consequently, also the noncalcareous division since these two appear to be more intimately related, at least in this area of study. These two divisions were set up initially for mapping purposes. The noncalcareous division includes calcareous beds and vice versa; and both comprise marine and nonmarine sediments. It is suggested here that these two units are at least partly related to each other by lateral facies change and that both overlie the laumontitized division. In comparison, by virtue of the intercalated tuffs and bentonites, the laumontitized unit may be more properly regarded as a chronologically constrained facies. This would support the hypothesis of waning arc volcanism, followed by rapid basin subsidence and infill since the laumontitized division is entirely terrestrial, while the other units are dominated by deltaic and delta-top deposition.

Pilot Station Area

Location 1

This sequence (see figure 13 and location map figure 12) is dominated by siltstones and units of thinly interbedded siltstones, fine-grained sandstones and claystones. Pervasive heterolithic bedding (mostly flaser) and abundant bioturbation (crawling traces and U-shaped burrows, including some with spreite) are strong indications of deposition within an intertidal flat environment, with flaser bedding resulting from rapidly changing current velocities, and the burrow spreite a response to altering depth from the sediment surface.

Sandstones at the top of the exposure, with highly erosive bases, poor sorting, and massive intervals are interpreted to be the deposits of small channels meandering across the flats. Rare stem imprints up to 1.5 m diameter occur in these sands.

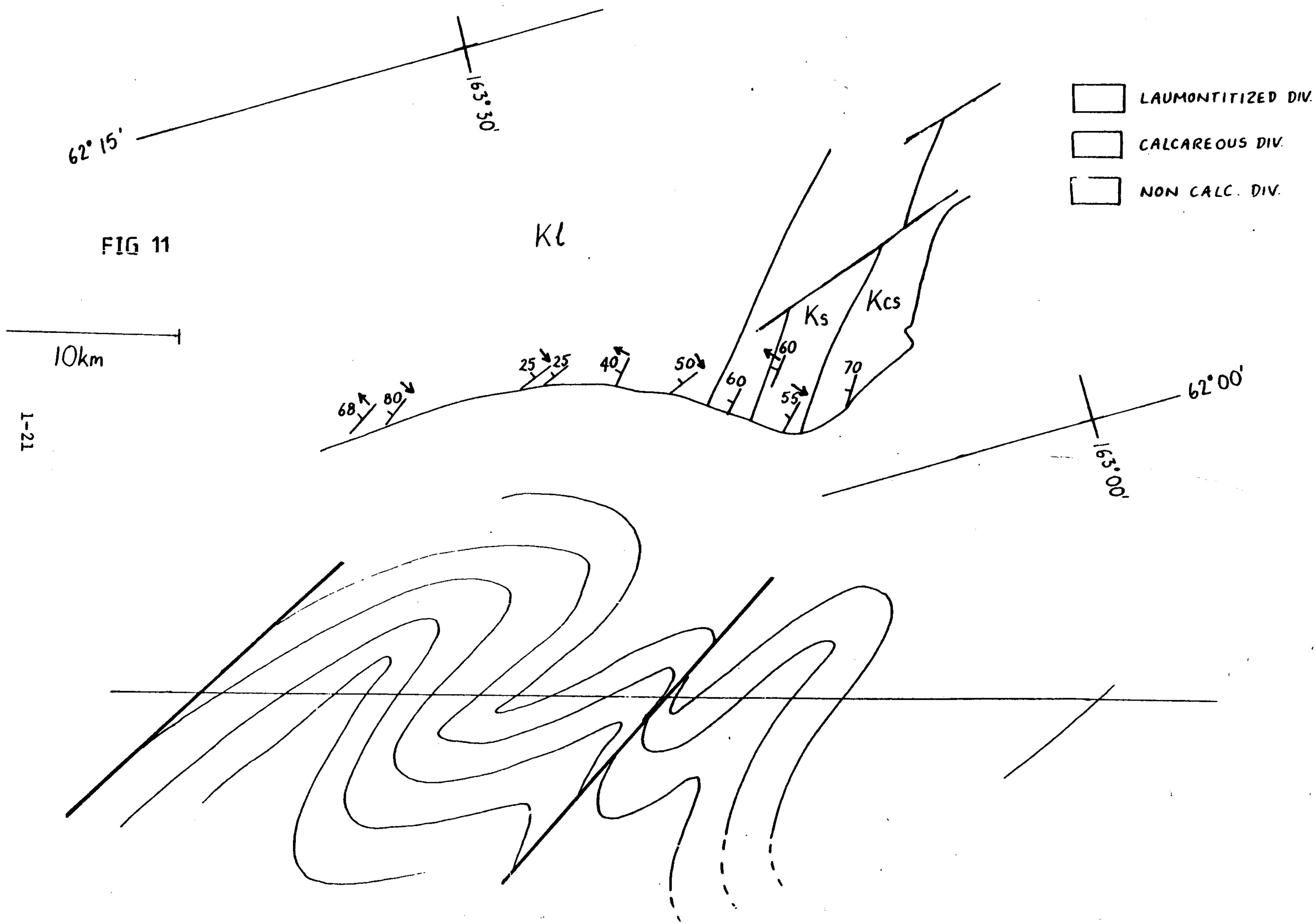

LAUMONTITIZED DIV.
CALCAREOUS DIV.
NON CALC. DIV.
62° 15'
163° 30'
62° 00'
163° 00'
Kl
Ks
Kcs
68
80
25
25
40
50
60
60
55
70
10km

FIG 11

FIG 12

PILOT STATION

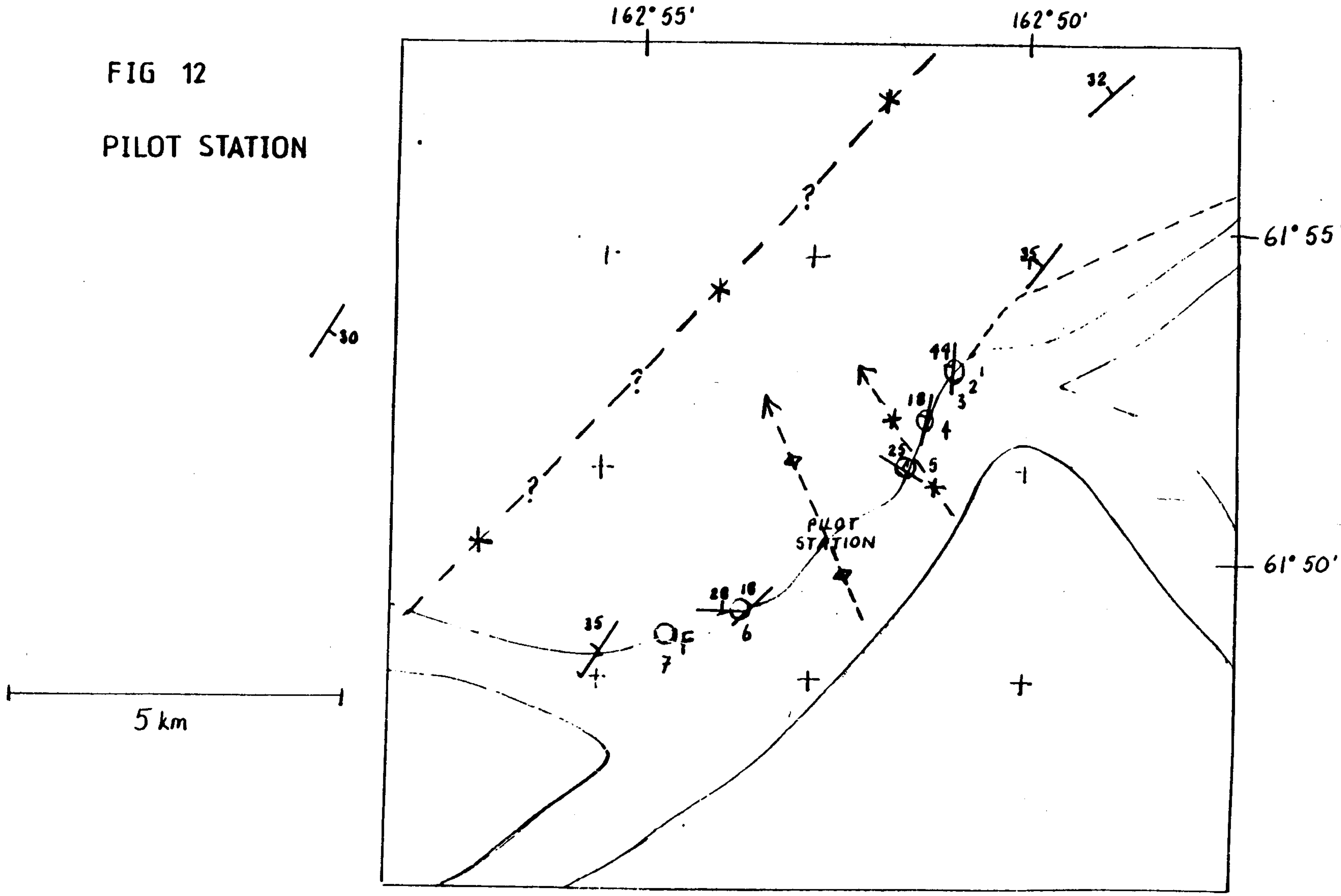
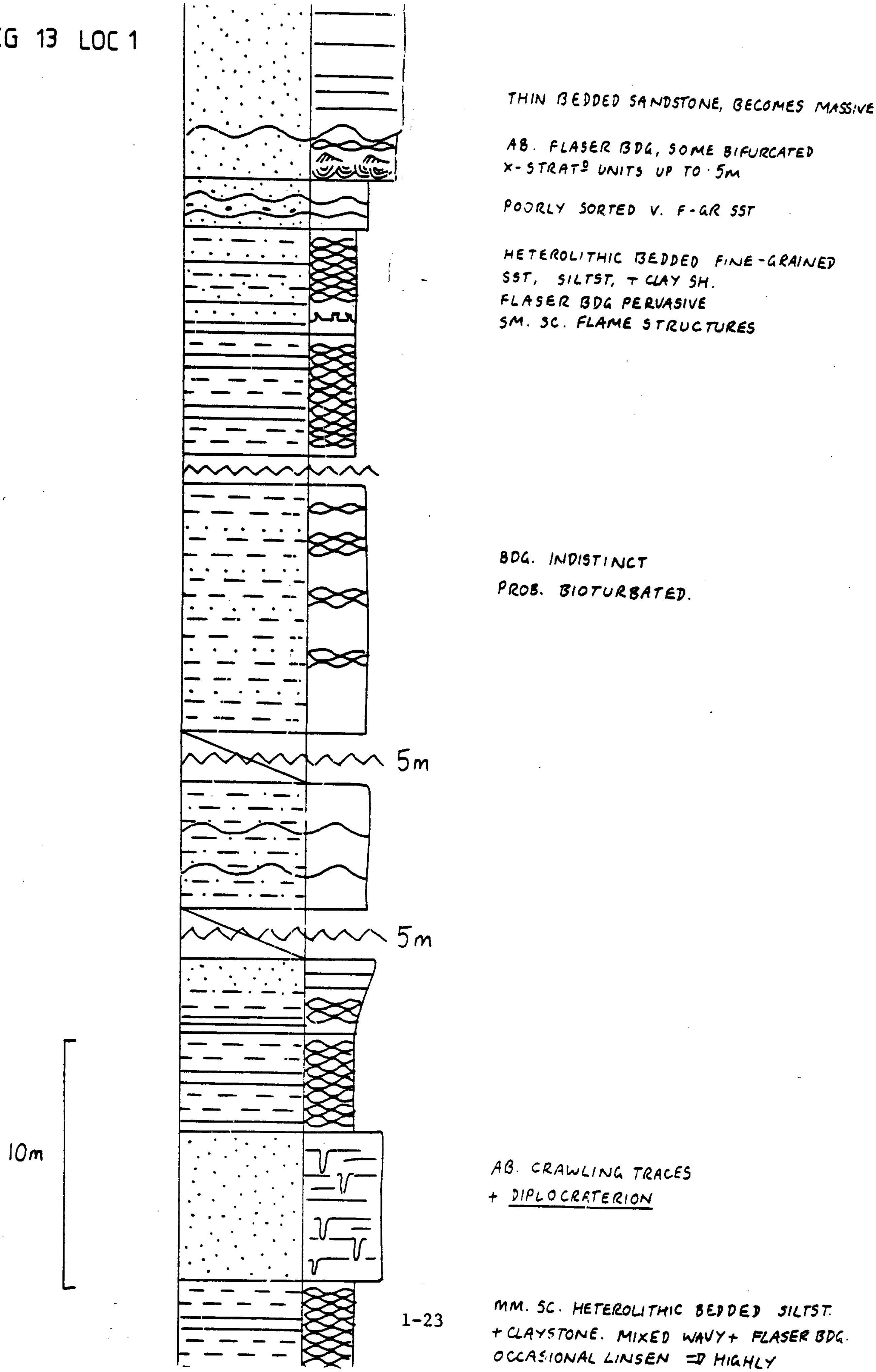


FIG 13 LOC 1


THIN BEDDED SANDSTONE, BECOMES MASSIVE
AB. FLASER BDG, SOME BIFURCATED X-STRAT$^{\underline{o}}$ UNITS UP TO ·5m
POORLY SORTED V. F-GR SST
HETEROLITHIC BEDDED FINE-GRAINED SST, SILTST, + CLAY SH.
FLASER BDG PERVASIVE
SM. SC. FLAME STRUCTURES
BDG. INDISTINCT
PROB. BIOTURBATED.
5m
5m
10m
AB. CRAWLING TRACES + DIPLOCRATERION
1-23
MM. SC. HETEROLITHIC BEDDED SILTST. + CLAYSTONE. MIXED WAVY + FLASER BDG. OCCASIONAL LINSEN ⇒ HIGHLY

Localities 2 and 3 are situated at intervals of around 30 and 50 m to the west of locality 1.

Locality 2

This locality consists of a section of similarly heterolithic bedded, dominantly silty units as above. Surface crawling traces are abundant and several bivalve specimens were recovered.

Locality 3

This is a small exposure, 12 m thick, which shows a slight coarsening-up progression. Fifty percent of the lower siltstones are very slightly calcareous, mid- to dark gray, and coarse-grained, while the remainder are dark gray, slightly micaceous and fine-grained. Generally, the two are interbedded on a mm scale, with flaser bedding abundant. A fine-grained sandstone horizon shows some grading bedding, cm scale slump folds, and sand balls. The upper siltstones are thicker bedded (cm to dm scale), and include intercalcated fine-grained sandstone beds up to .6 m thick with small clay pebbles.

Locality 4

Locality 4, several hundred meters downstream from locality 3, comprises very similar material, although some coarser sediment is present and flaser bedding is somewhat less pervasive.

Locality 5

This locality may be regarded as identical in character to locality 4.

Locality 6

This sequence shows a variety of related delta-top facies, intertidal flats, and channels and sandbar with a dramatic increase in sandstone contentcompared with the previous localities (see figure 14). The thick sandstone is a fine-grained, pale greenish-gray wacke. Grains are subrounded and the sorting fair. The orientation of occasional carbonaceous streaks is parallel to the foreset laminae of faint cross-stratification.

Locality 7

The sediments here represent high sinuousity (meandering) channel and accompanying overbank deposits (see figure 15), which include a thin coal bed. The channel sandstone yields dominantly platanoid type leaves in addition to Ginkgo minor and G. digitata, occasional Podozamites, and entire margin forms. In comparison, the siltstones contain well preserved conifer shoots, platanoid leaf fragments, Podozamites and Sequoia

FIG 14 LOC 6

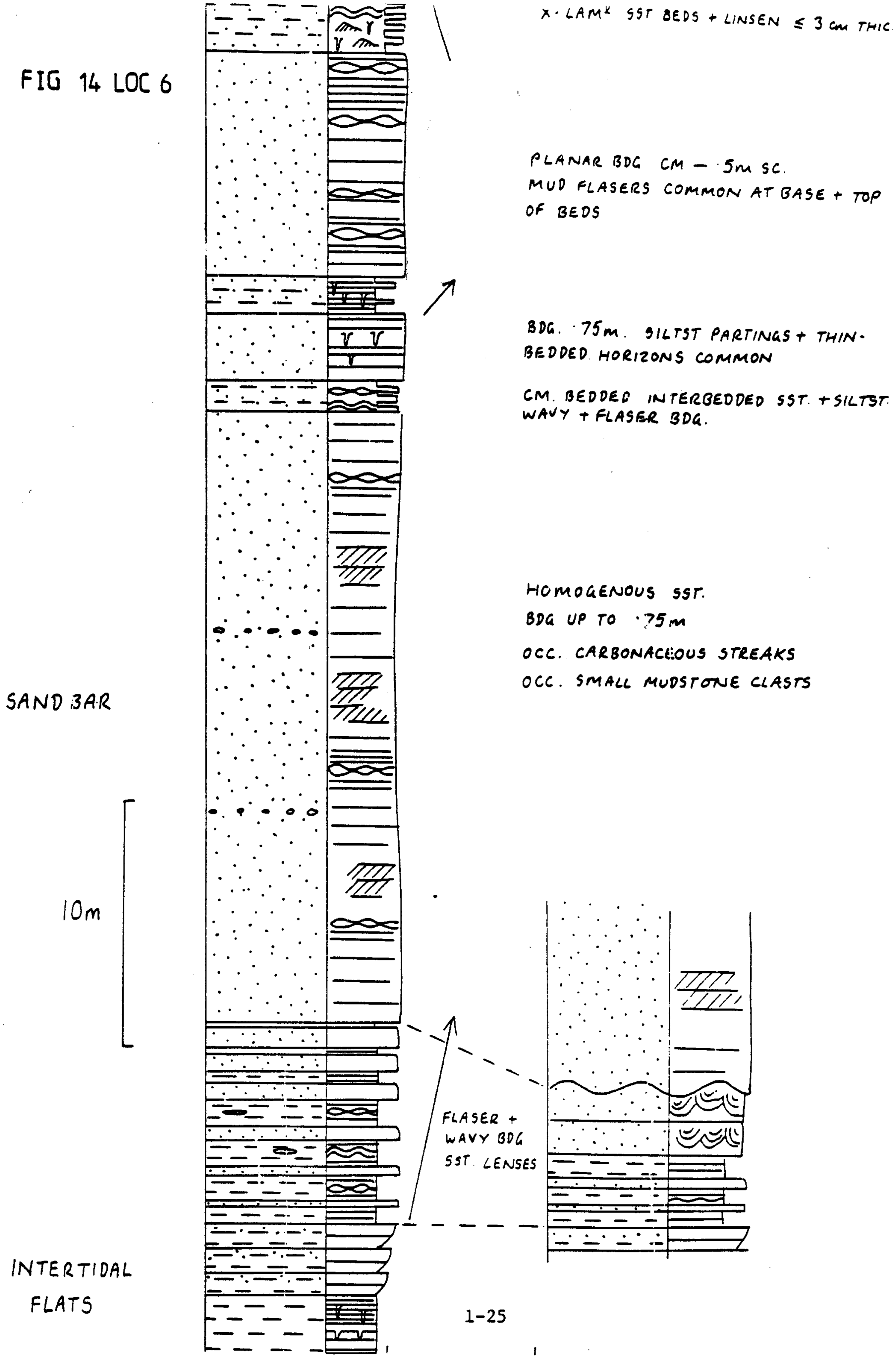
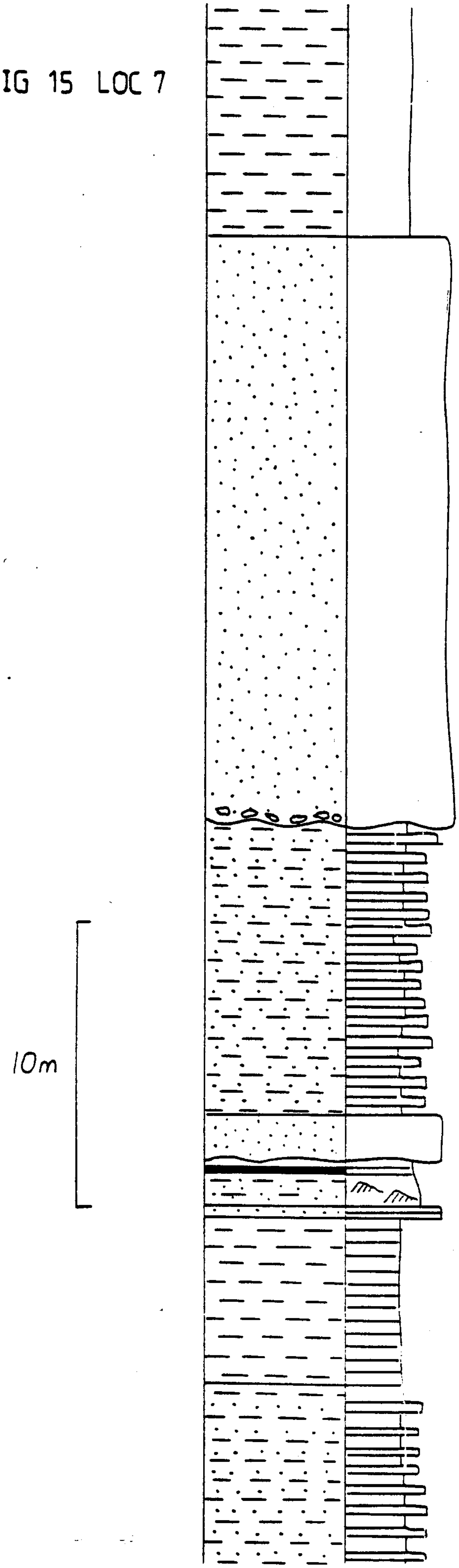

X-LAM^k SST BEDS + LINSEN ≤ 3 cm THIC
PLANAR BDG CM — ·5m SC.
MUD FLASERS COMMON AT BASE + TOP OF BEDS
BDG. ·75m. SILTST PARTINGS + THIN-BEDDED HORIZONS COMMON
CM. BEDDED INTERBEDDED SST + SILTST. WAVY + FLASER BDG.
HOMOGENOUS SST.
BDG UP TO ·75m
OCC. CARBONACEOUS STREAKS
OCC. SMALL MUDSTONE CLASTS
SAND BAR
10m
FLASER + WAVY BDG SST. LENSES
INTERTIDAL FLATS

FIG 15 LOC 7


10m
MASSIVE SST
FLOAT PROVIDES LG. NUMBER OF DOMINANTLY PLATANOID TYPE LEAVES.
ALSO GINKGO MINOR + G. DIGITATA
+ OCC. ENTIRE MARGIN FORM
+ OCC PODOZAMITES
LAG DEPOSIT - ROUNDED VEIN QUARTZ PEBBLES
THIN COAL
SILTY SST WITH RIPPLED SURFACES
WELL PRESERVED CONIFER SHOOTS, PLATANOID LEAF FRAGMENTS, SEQUOIA + PODOZAMITES
INTERBEDDED SILTST. SST + SILTY SST
? FLOAT SHOWS RARE MOLLUSCS

APPENDIX 2
BLM's Mineral Potential Classification System
Mineral Potential Classification System

I. Level of Potential

O. The geologic environment, the inferred geologic processes, and the lack of mineral occurrences do not indicate potential for accumulation of mineral resources.

L. The geologic environment and the inferred geologic processes indicate low potential for accumulation of mineral resources.

M. The geologic environment, the inferred geologic processes, and the reported mineral occurrences or valid geochemical/geophysical anomaly indicate moderate potential for accumulation of mineral resources.

H. The geologic environment, the inferred geologic processes, the reported mineral occurrences and/or valid geochemical/geophysical anomaly, and the known mines or deposits indicate high potential for accumulation of mineral resources. The "known mines and deposits" do not have to be within the area that is being classified, but have to be within the same type of geologic environment.

ND. Mineral(s) potential not determined due to lack of useful data. This notation does not require a level-of-certainty qualifier.

II. Level of Certainty

A. The available data are insufficient and/or cannot be considered as direct or indirect evidence to support or refute the possible existence of mineral resources within the respective areas.

B. The available data provide indirect evidence to support or refute the posssible existence of mineral resources.

C. The available data provide direct evidence, but are quantitatively minimal to support or refute the possible existence of mineral resources.

D. The available data provide abundant direct and indirect evidence to support or refute the possible existance of mineral resources.

For the determination of No Potential, us O/D. This class shall be seldom used, and when used, it should be for a specific commodity only. For example, if the available data show that the surface and subsurface types of rock in the respective area is batholithic (igneous intrusive), one can conclude, with reasonable certainty, that the area does not have potential for coal.

*As used in this classification, potential refers to potential for the presence (occurrence) of a concentration of one or more energy and/or mineral resources. It does not refer to or imply potential for development and/or extraction of the mineral resource(s). It does not imply that the potential concentration is or may be economic, that is, could be extracted profitably.

APPENDIX 3

Oil and Gas Demand and Supply Relationship

The importance of potential oil and gas resources from this refuge is dependent on the hydrocarbon potential of the area, national need for additional sources of oil and gas, and the economics of exploring and producing any hydrocarbons that might be discovered. This Appendix provides a detailed review of the factors that have contributed to the present domestic oil and gas situation and possible future demand for oil and gas, which is directly linked to the national need for oil and gas resources from the refuge.

Domestic Energy Trends

The domestic energy situation, as it relates to oil and gas consumption and production, has changed dramatically since the early 1970s. In 1970, petroleum and natural gas supplied 44 and 33 percent (United States Department of Energy, Energy Information Administration, 1984), respectively, of the total energy consumed in the United States (figure 1). By 1977, petroleum accounted for nearly 49 percent of domestic energy consumption, and natural gas consumption had declined to approximately 26 percent of total energy demands. The relative contribution of both petroleum and natural gas declined through 1985, when petroleum supplied nearly 42 percent, and natural gas contributed approximately 25 percent of total energy demand. Figure 1 shows the contribution of each major primary energy source to total national energy demand in 1970, 1980, and 1985. Coal, nuclear, and geothermal energy were the primary forms of energy to increase their market share of total energy consumption during this time period, at the expense of petroleum and natural gas resources.

Total domestic energy consumption peaked at 78.9 quadrillion (QUAD) British thermal units (BTU) in 1979 and subsequently declined to 73.8 QUADS in 1985 (United States Department of Energy, Energy Information Administration, 1986). Over the 15-year period from 1970 to 1985, total primary energy consumption increased 11 percent, from 66.4 QUADS to 73.8 QUADS; however, the rapid increase in energy consumption and escalation in the cost of energy (the cost of energy more than doubled, from 1.35 constant 1972 dollar per million BTU in 1970 to 2.90 in 1981) during this time period resulted in a dramatic change in national energy consumption patterns. Total energy consumed per constant 1972 dollar of Gross National Product (GNP) ranged from 56,500 to 61,000 BTUs per 1972 dollar of GNP from 1950 through 1976 (United States Department of Energy, Energy Information Administration, 1985a). A decline in the intensity of energy utilization was realized in 1977, when total energy consumption dropped to 55,700 BTUs per dollar of GNP, and this downward trend continued through 1985, when energy consumption was reduced to 42,900 BTUs per 1972 dollar of GNP (United States Department of Energy, Energy Information Administration, 1986). The decline in energy consumption was led by the

FIGURE 1
PRIMARY ENERGY CONSUMPTION BY SOURCE

FIGURE 1A
1970
Total = 65.4 Quadrillion Btu

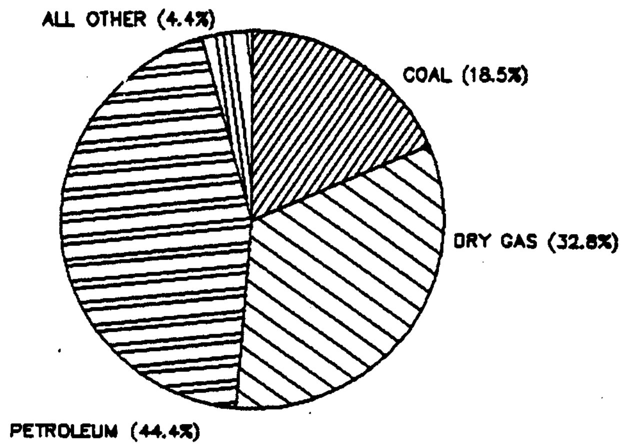


FIGURE 1B
1980
Total = 75 Quadrillion Btu

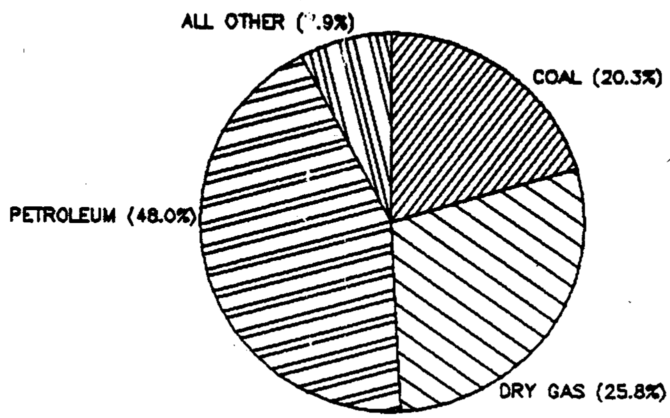
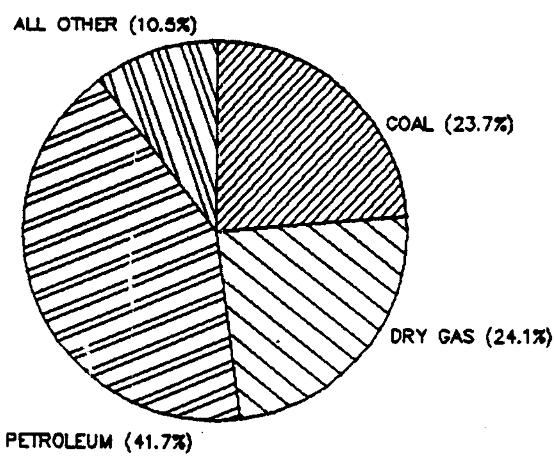


FIGURE 1C
1985
Total = 73.5 Quadrillion Btu



reduction in the intensity of petroleum and natural gas utilization. In 1985, only 68 percent as much petroleum and natural gas were consumed per dollar of GNP than in 1977, as compared to 77 percent for total energy consumption. The reduction in intensity of energy utilization was indicative of a national conservation effort which any be attributed to many factors, including: increased real energy prices, the increased service orientation of the economy, and changes in the mix of product production (United States Department of Energy, Energy Information Administration, 1985a).

Historical Oil and Gas Demand, Supply, and Price Relationships

The relationship between price and domestic petroleum supply and demand is shown in figures 2 and 3. Import prices utilized for petroleum in figure 3 are represented by the national average refiner's acquisition cost of imported crude oil, and wellhead prices are presented on the basis of the national average from all producing wells. Domestic crude oil prices were not completely decontrolled until January 1981 and, therefore, domestic wellhead prices do not follow import prices during the 1970s. Petroleum product demand rose throughout the early 1970s, until it peaked at 18.8 million barrels per day (MBPD) in 1978 (United States Department of Energy, Energy Information Administration, 1986a). Crude oil price increases began with the Arab oil embargo in 1973, and a second major price run-up was triggered in 1978 by the Iranian revolution and subsequent oil stock building in anticipation of world oil shortages. Real import prices peaked at $44.00 per barrel (1985 dollars) in 1980.

Domestic petroleum product demand began a downward slide in 1979 which continued through 1983. The Organization of Petroleum Exporting Countries (OPEC) members sought to maintain the higher prices, that resulted from oil price shocks of the 1970s, by production restraints. However, oil prices have steadily declined since 1981 as a result of slow economic growth with subsequent declining petroleum demand and excess world productive capacity (United States Department of Energy, Energy Information Administration, 1986b). Domestic oil prices in the second quarter of 1986 had declined to the lower teens in nominal terms, which is comparable to 1974 prices in real dollars. Figures 2 and 3 show that petroleum demand is sensitive to price and is characterized by long lags and high elasticities.

Domestic petroleum production has been much more stable than petroleum product demand. Figure 2 shows that Alaskan production, primarily from the North Slope, contributes a significant portion of domestic supply. In 1985, Alaska accounted for more than 20 percent of the national crude oil production (United States Department of Energy, Energy Information Administration, 1986a). Price increases of the 1970s provided incentive for exploration and production from higher cost areas such as Alaska. Foreign imports have been required to fill the gap between domestic supply and demand. Crude oil and petroleum product imports peaked in 1977, when net imports accounted for more

FIGURE 2
NATIONAL PETROLEUM DEMAND
AND SUPPLY 1970 – 1985

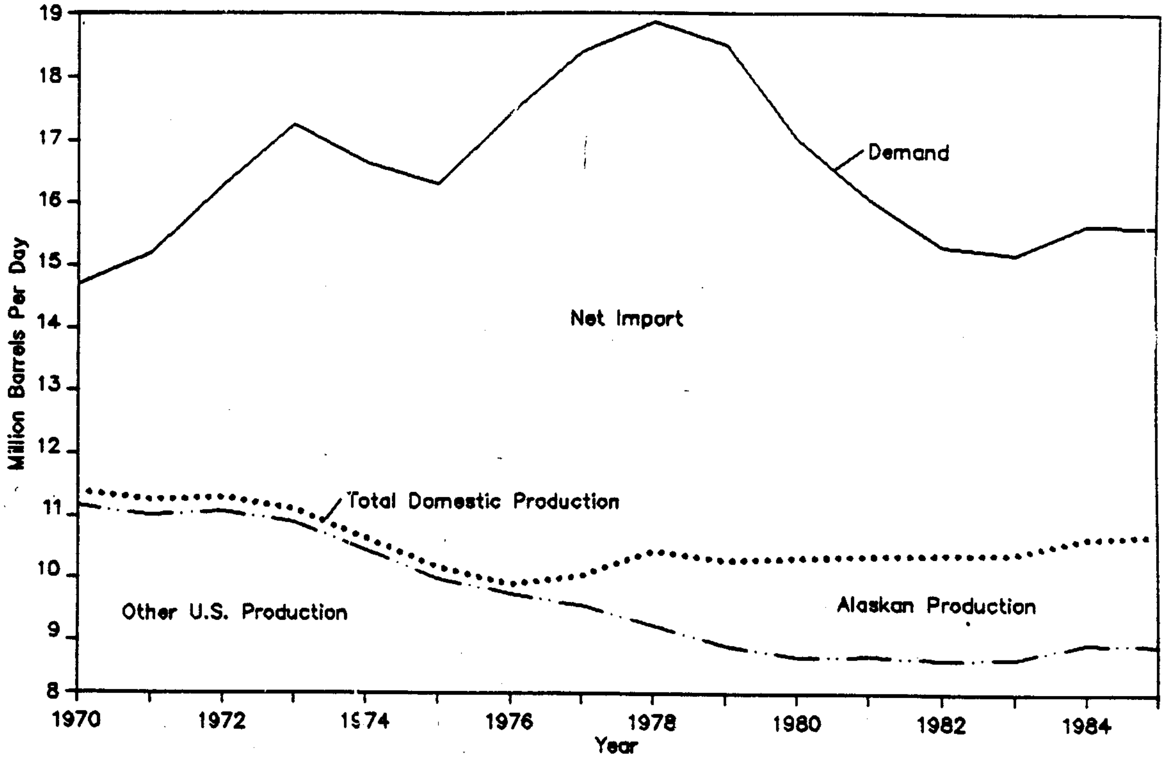
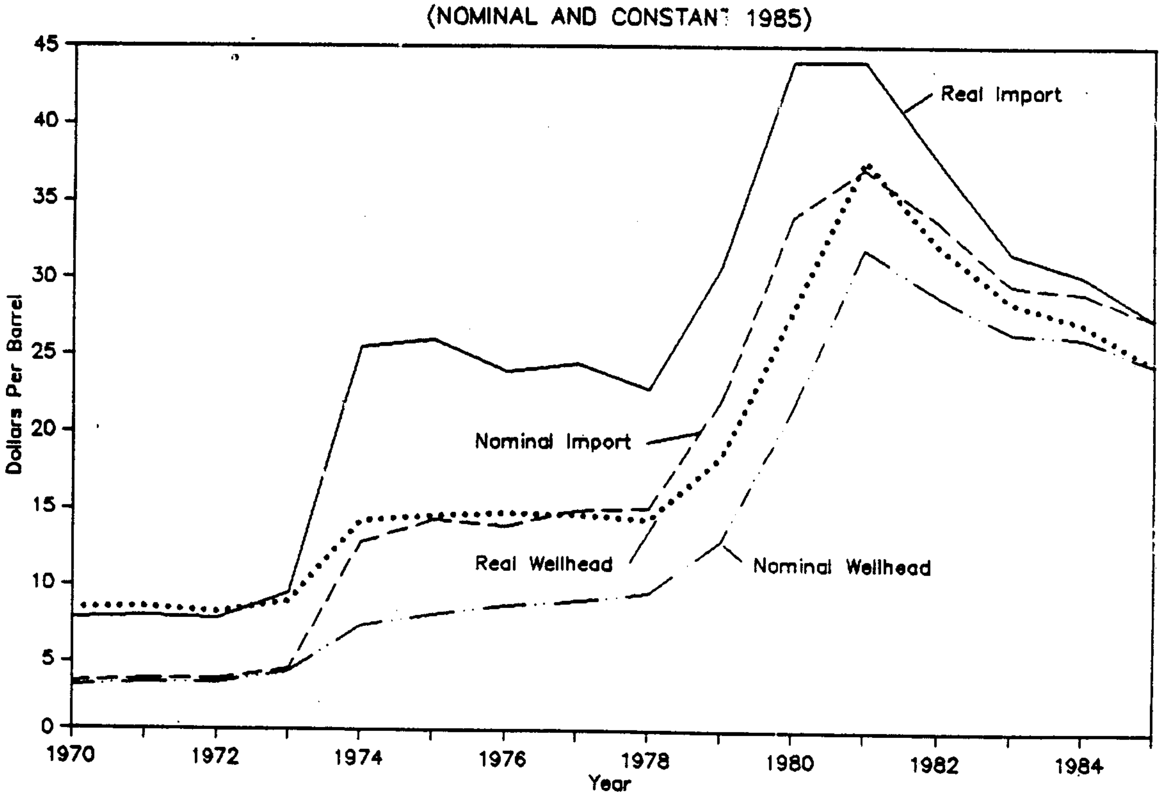


FIGURE 3
CRUDE OIL PRICES
(NOMINAL AND CONSTANT 1985)



than 46 percent of domestic petroleum consumption. Net petroleum import levels declined to 27 percent of product demand in 1985, but the United States still remains highly dependent of foreign petroleum supply sources.

The history of natural gas production and consumption in the United States is quite different from petroleum, and it has a direct bearing on gas pricing policies, demand, and supply relationships in the 1970s and 1980s (figures 4 and 5). Natural gas went from a little used waste by-product of oil production in the 1930s to a source of energy that supplied nearly 33 percent of national consumption in 1970 (figure 1). By 1970, gas was being delivered to consumers at prices well below those of competing petroleum products (United States Department of Energy, Energy Information Administration, 1984). Prices paid to gas producers by interstate pipeline companies were held at low levels through regulation by the Federal Power Commission, which resulted in increased demand and reduced incentives for producers to explore and develop new gas reserves. Regulated prices allowed intrastate transmission companies and distributors to bid natural gas supplies away from interstate carriers (Tussing and Barlow, 1984). The 1970s has been noted for the gas supply shortages in the midwest and northern states. Imported gas prices increased in a pattern similar to oil prices, but domestic prices remained under regulation. The Natural Gas Policy Act was passed in 1978, which allowed wellhead prices to increase and it deregulated certain categories of gas. Price increases provided incentives to explore and develop new sources of gas. Natural gas consumption started a sharp decline after 1980 under the influence of higher gas prices, a weak economy, warm winters, and, since 1981, falling oil prices (United States Department of Energy, Energy Information Administration, 1984). This trend continued through 1985, with the exception of a small increase in gas demand realized in 1981, which may be attributed to the strong economic growth in the national economy in that year.

Net imports of natural gas are primarily received through pipelines from Canada and Mexico, although there are some liquified natural gas (LNG) imports from Algeria. Net imports generally ranged near five percent from 1970 to 1985. Alaska is a relatively small producer of natural gas, ranging from approximately 100 to 325 billion cubic feet per year from 1970 to 1985 (United States Department of Energy, Energy Information Administration, 1985b).. Alaska is, however, a net exporter of natural gas in the form of LNG, which is delivered to Japan. Huge gas reserves have been identified on the Alaskan North Slope, but this resource has not been commercially produced due to a lack of transportation infrastructure.

Future Oil and Gas Demand, Supply, and Price Relationships

From the review of historic petroleum and natural gas price, demand, and supply relationships, it is apparent that there have been fundamental changes, such as petroleum price deregulation and energy conservation efforts in the national energy market since the early 1970s that will likely affect future

FIGURE 4
NATIONAL NATURAL GAS DEMAND
AND SUPPLY 1970 – 1985

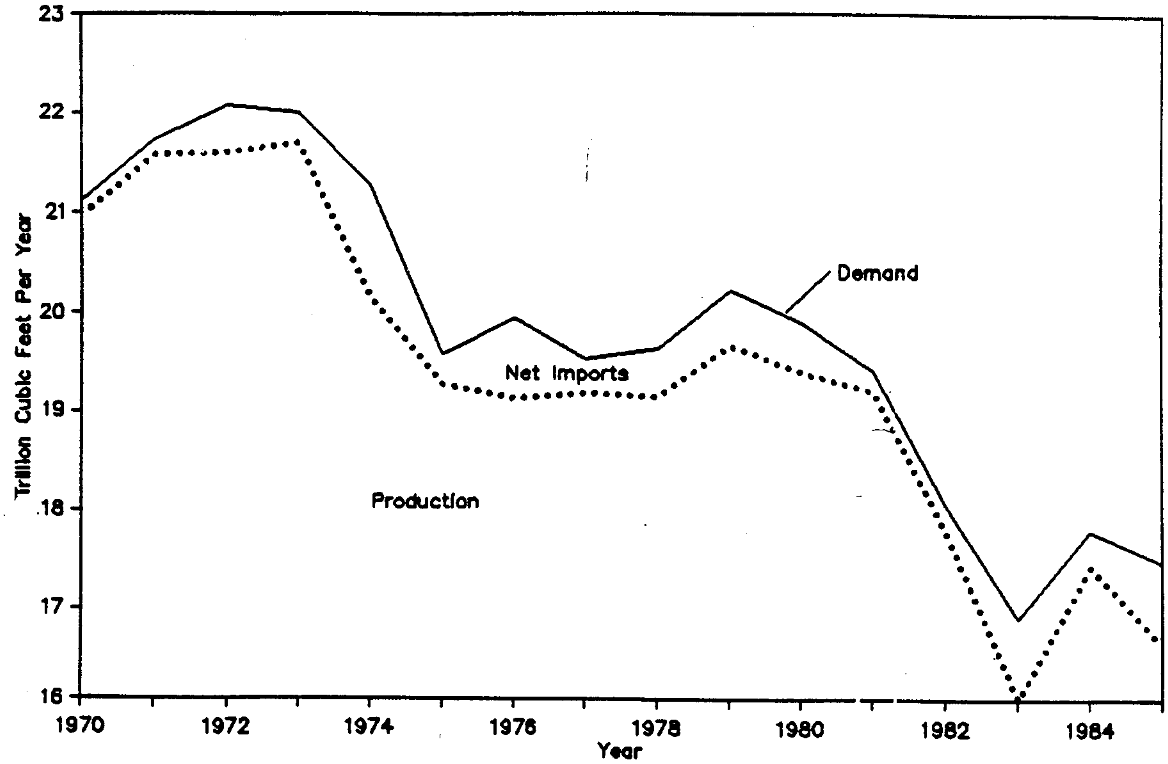
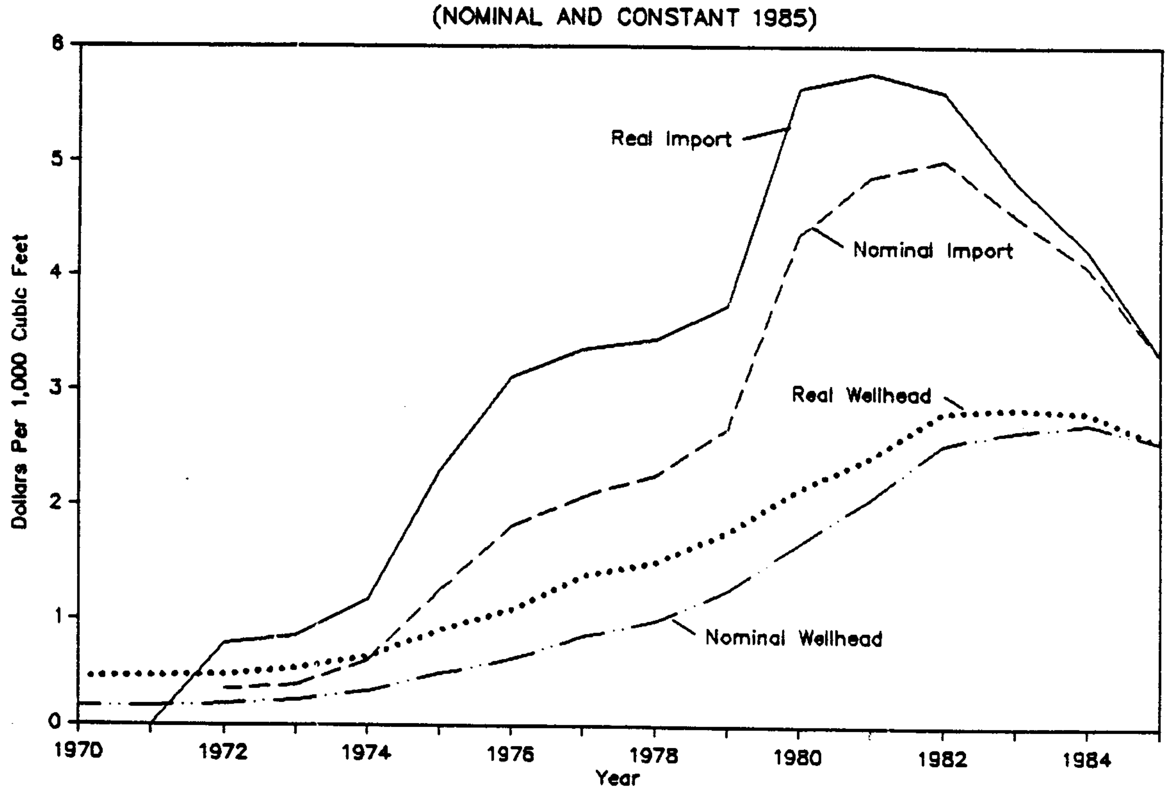


FIGURE 5
NATURAL GAS PRICES
(NOMINAL AND CONSTANT 1985)



petroleum and natural gas production and consumption. At the present time, the national petroleum market is directly linked to the world petroleum market by price and supply. The situation is characterized by excess productive capacity in the world market, a strong desire by exporting nations to sell petroleum to meet financial obligations, a time of relatively slow economic growth, and declining petroleum prices. The domestic natural gas industry is currently working off surplus reserves added during the early 1980s, but depressed prices have resulted in a sharp reduction in drilling which could have serious implications for future domestic gas production.

Implications of the petroleum price slide during the first half of 1986 are not yet fully discernable. Middle eastern nations have been unable to reach accord in setting and adherence to self-imposed oil production quotas. In the past, Saudi Arabia has taken the position as swing producer for OPEC, and thereby reduced production to maintain quota levels. However, Saudi Arabia changed policies in 1986 to concentrate on achieving a "fair market share" of the international petroleum market with little concern for output quotas. The strategy behind this policy was not disclosed, but speculation as to the potential motivation and results of this action includes:

1. Saudi Arabia is making a show of strength to discipline OPEC members that have cheated on production quotas and prices with hopes of bringing member and possibly non-member nations together as a unified market group;

2. Saudi Arabia sought to increase revenue, but underestimated the effects additional production would have on price;

3. Saudi Arabia is flooding the world oil market in an effort to eliminate producers with higher costs of production and thereby reduce competition;

4. Saudi Arabia is acting to reduce prices and stimulate growth in petroleum demand to reverse conservation efforts initiated in the late 1970s and 1980s.

In any event, a tremendous amount of uncertainty exists in the national petroleum industry, which has resulted in major financial restructuring. The most evident signs of restructuring are major employment reductions and reduced capital expenditures for exploration and drilling.

The interest in mineral exploration and possible development in this refuge is driven by the future national demand for oil and gas, the cost and availability of domestic supplies, and the hydrocarbon potential of the area. The rate of future economic growth and hydrocarbon prices will be the major determinants of petroleum and natural gas demand. Future domestic production is dependent on resource availability and market prices. However, political forces are having an increasingly important effect on world oil prices, which will ultimately dictate future market conditions. The instability in the world oil market results in tremendous uncertainty in predicting future

TABLE 1

PETROLEUM AND NATURAL GAS PRICE FORECASTS1/

Reference	Crude Oil ($/Barrel) 1990	2000	2010	Natural Gas ($/MCF) 1990	2000	2010
U.S. Department of Energy, 19852/						
Low Economic Growth	20.27	31.31	47.42	2.64	4.13	6.02
Reference Case	22.89	36.75	56.77	2.76	4.80	7.68
High Economic Growth	25.02	42.17	67.12	2.88	5.42	9.14
Data Resources Incorporated, 19862/	16.91	34.32	49.99	1.69	3.80	5.76
Chevron Corporation, 19863/						
Low Case	12.00	18.00	N/A	Rise to parity with fuel oil prices		
High Case	27.50	35.00	N/A			

1/ Some of the price estimates presented in this table were interpreted from graphic displays and/or extrapolated from data series, so the reported prices may vary slightly from the actual values.

2/ Reported on the basis of constant 1984 dollars.

3/ Reported on the basis of constant 1985 dollars.

hydrocarbon prices and market conditions. Table 1 presents three recent crude oil and natural gas price forecasts by the United States Department of Energy, a private research firm, and a major oil company. The prices shown in these forecasts are significantly lower than previous forecasts completed earlier in the 1980s. The range of oil prices projected in these forecasts is $18.00 to $42.00 (constant 1984 and 1985 dollars) per barrel in the year 2000. The high price range is approximately equivalent to the average annual refiner's acquisition cost of imported crude received in 1981 and 1982 (constant 1984 dollars). The range of prices projected for the year 2010 is $47.00 to $67.00 per barrel. These prices would be substantially above the peak levels paid in the early 1980s. Natural gas prices are projected to range between $4.10 and $5.50 per thousand cubic feet (MCF) in the year 2000, and $6.00 to $9.10 per MCF in the year 2010. The magnigude of projected natural gas price increases is similar to forecast changes in world oil prices.

Projections of future domestic petroleum and natural gas demand and supply conditions is presented in table 2. All three forecasts projected an upward trend in petroleum demand above current levels. Petroleum consumption is projected to range from 15.9 to 18.1 MBPD in the year 2000, and possibly increase to 19.4 MBPD by the year 2010. In comparison, domestic petroleum production is projected to decline to levels ranging from 6.1 to 8.9 MBPD by the year 2010. Domestic natural gas demand is projected to increase to a level ranging from 17.1 to 20.4 TCF per year by the year 2000 and then decline to a level of 16.7 to 18.3 per year by 2010. Domestic gas production is projected to follow a similar trend with domestic oil production and decline to levels ranging from 13.9 to 15.0 TCF by the year 2010.

Conclusion

National hydrocarbon markets have undergone substantial changes since the early 1970s. Energy conservation trends initiated by real price increases of the 1970s are expected to continue through the end of this decade and possibly beyond. However, future economic growth is expected to result in some increased demand for petroleum and natural gas, while domestic production of these finite resources is projected to decline. As a result, the United States will become increasingly dependent on foreign hydrocarbon sources to meet national requirements. New areas will need to be explored and any economically viable resources that are discovered will need to be brought into production in order to meet domestic needs. The potential contribution of this refuge to national oil and gas production is dependent on its resource potential and the potential cost at which any discovered hydrocarbon resources could be extracted and marketed within the constraints of future oil and gas prices.

Table 1

Stratified Sedimentary Sequences
(includes some volcanic and metamorpthic)

Qh = Holocene deposits: alluvial, glacial, lake estuarine, swamp, flood plain, and beach deposits.
Q = Quaternary deposits: Alluvial, glacial, lake, eolian, beach, and volcanic deposits.
Op = Pleistocene Deposits: Alluvial, glacial, dune sands, loess and reworked sands and silts deposits.
K = Cretaceous rocks: Graywacke and shale of the Kuskokwim Group; volcanic graywacke, mudstone, siltstones of the Yukon-Koyukuk province.
lK = Lower Cretaceous rocks: Graywacke, shale, argillite, tuff, conflomerate, and minor limestone; includes the Buchia Ridge, Ungalikthluk, Mount Orantia, and Eek Mountains belts.
KJ = Cretaceous and Jurassic rocks: Argillite, shale, graywacke, volcanic graywacke, quartzite, conglomerate, lava, tuff. Ranges from Early Jurassic to Late Cretaceous.
mJ = Middle Jurassic rocks: Argillite, volcanic graywacke, conglomerate.
MzPz = Mesozoic and Paleozoic rocks: Argillite, cherts, limestone, quarzite, schist, slate, and interbedded marble in the Togiak area and greenstone metasedimentary rocks in the Yukon-Koyukuk area ranges from Ordovician to Jurassic.
D = Devcnian rocks: Limestone east of Kukkokwim Bay.
lPz = Lower Paleozoic rocks: Includes limestone, dolomite, argillite, chert, and graywacke and metasedimentary rocks, includes schist, quartzite, slate, greenstone, carbonate rocks and phyllite.
Z = Precambrian rocks: Metamorphic rocks of schist, gneiss, small amount of marble, amphibotite to greenschist facies.

Intrusive and Volcanic Rocks

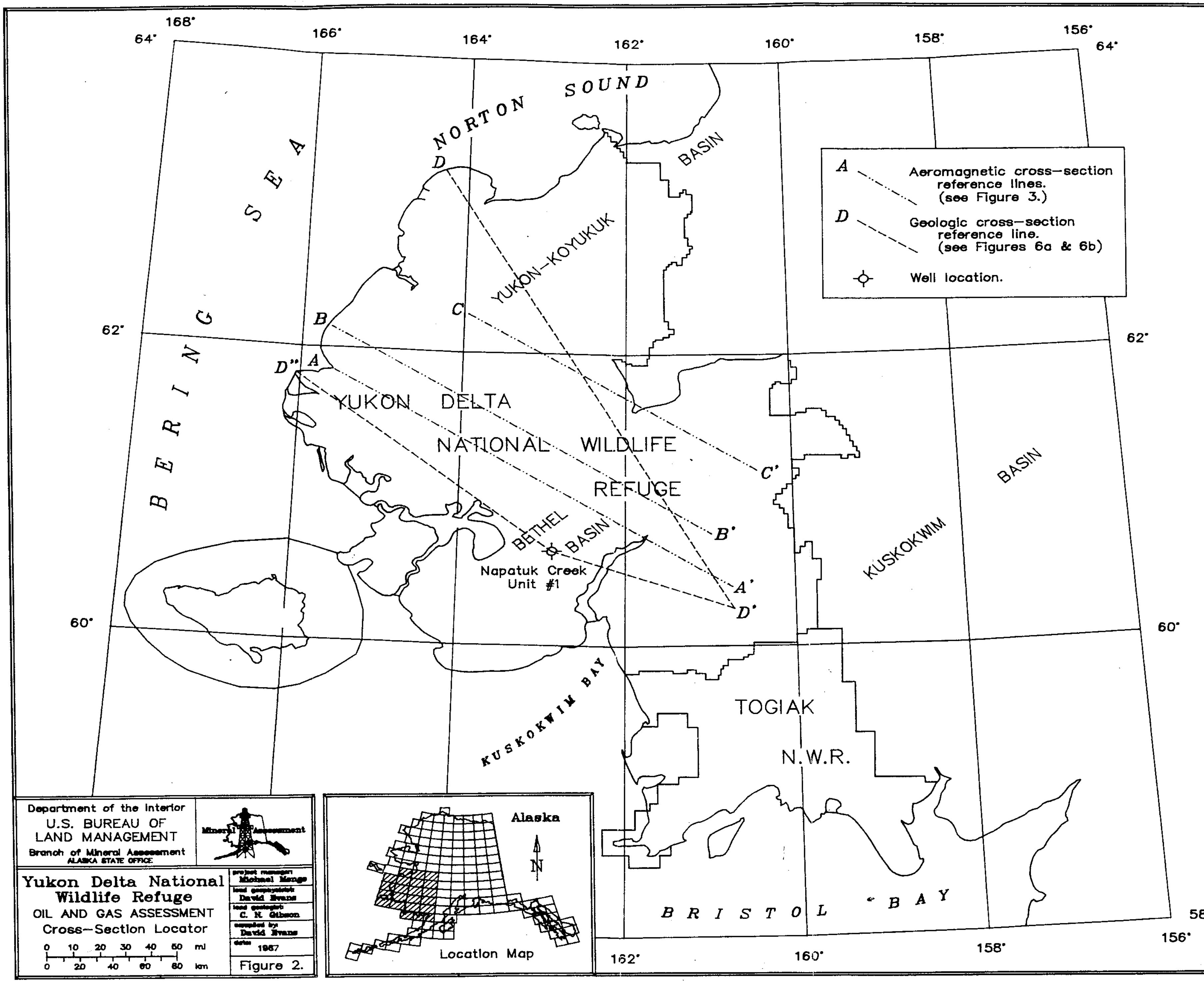
Ovm = Quaternary mafic volcanic, dominantly subarcal basalt flow.
OTvm = Quaternary and Tertiary, mafic volcanic subarcal basalt flow.
OTv = Quaternary and Tertiary, vundifferentiated volcanic rocks.
Tv = Tertiary volcanic, undifferentiated rocks.
Tim = Tertiary mafic intrusive.
Tif = Tertiary felsic intrusive, granite to granodiorate.
Tki = Tertiary and Cretaceous intrusive, undifferentiated.
Tkif = Tertiary and Cretaceous felsic intrusive, granite to grandiorate.
Kif = Cretaceous felsid intrusive, granite to grandiorate.
Kii = Cretaceous intermediate intrusive, syenite to diorate.
Kvi = Cretaceous volcanic andersitic.
KJv = Cretaceous and Jurassic volcanic, andesetic.
Jvi = Jurassic volcanic, ancersetic.
Jim = Jurassic mafic intrusive grabbro.

TABLE 2

FUTURE DOMESTIC PETROLEUM AND NATURAL GAS
DEMAND AND SUPPLY RELATIONSHIPS[1]
(See Table 1 for Price Forecasts)

Reference	Demand 1990	Demand 2000	Demand 2010	Supply 1990	Supply 2000	Supply 2010
	Petroleum (Millions of Barrels Per Day)					
U.S. Department of Energy, 1985						
Low Economic Growth	16.1	15.9	15.5	9.8	9.0	7.8
Reference Case	16.7	16.6	16.5	10.0	9.4	8.3
High Economic Growth	16.8	17.0	17.3	10.0	9.7	8.9
Data Resources Incorporated, 1986	16.9	18.1	19.4	9.5	7.3	6.1
Chevron Corporation, 1986	16.0	16.8	N/A	9.2	7.0	N/A
	Natural Gas (Trillion Cubic Feet Per Year)					
Department of Energy, 1985						
Low Economic Growth	18.6	18.8	17.2	17.4	16.1	14.7
Reference Case	19.1	19.7	17.4	17.6	16.3	15.0
High Economic Growth	19.5	20.4	18.3	17.9	16.6	14.7
Data Resources Incorporated, 1986	18.9	18.1	16.7	16.7	15.3	13.9
Chevron Corporation, 1986	17.3	17.1	N/A	N/A	N/A	N/A

[1] Some of the numeric estimates presented in this table were interpreted from graphic displays and/or extrapolated from data series, so the reported prices may vary slightly from the actual values.



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ALASKA STATE OFFICE

Mineral Assessment

Yukon Delta National Wildlife Refuge
OIL AND GAS ASSESSMENT
Cross-Section Locator

project manager: Michael Menge
lead geophysicist: David Evans
lead geologist: C. N. Gibson
compiled by: David Evans
date: 1987

0 10 20 30 40 50 mi
0 20 40 60 80 km

Figure 2.

LEGEND

D	=	Devonian Rocks
lK	=	Lower Cretaceous Rocks
lPz	=	Lower Paleozoic Rocks
Jim	=	Jurassic mafic intrusive
JPvm	=	Jurassic & Permian mafic volcanic
Jvi	=	Jurassic intermediate volcanic
K	=	Cretaceous Rocks
Kif	=	Cretaceous felsic intrusive
Kii	=	Cretaceous intermediate intrusive
KJ	=	Cretaceous & Jurassic Rocks
Kvi	=	Cretaceous intermediate volcanic
KJv	=	Cretaceous & Jurassic volcanic
mJ	=	middle Jurassic
MzPz	=	Mesozoic & Paleozoic Rocks
Q	=	Quaternary Deposits
Qh	=	Holocene Deposits
Qp	=	Pleistcene Deposits
QTvm	=	Cenezoic mafic volcanic
Qvm	=	Quaternary mafic volcanic
T	=	Tertiary Rocks
TKi	=	Tertiary & Cretaceous intrusive
TKif	=	Tertiary & Cretaceous felsic intrusive
Tif	=	Tertiary felsic intrusive
Tim	=	Tertiary mafic intrusive
Tv	=	Tertiary volcanic
Tvm	=	Tertiary mafic volcanic
u	=	Undifferentiated
Z	=	Precambrian Z Rocks

After:

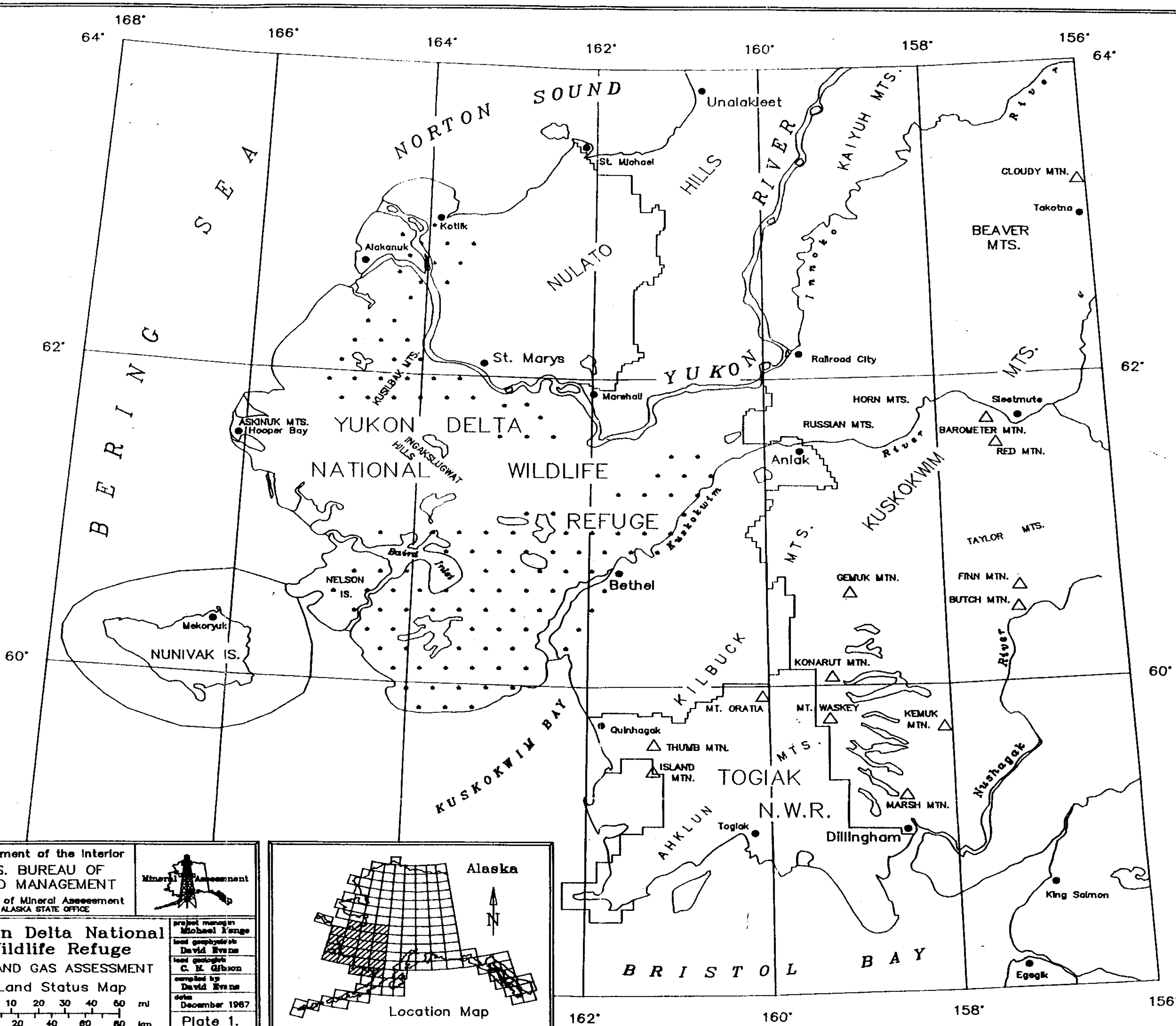
GEOLOGIC MAP OF ALASKA

State of Alaska Dept. of Natural Resources
Division of Geological & Geophysical Surveys

HELEN M. BEIKMAN, 1980

Table 2.

Geology Map Key for Plate 2.



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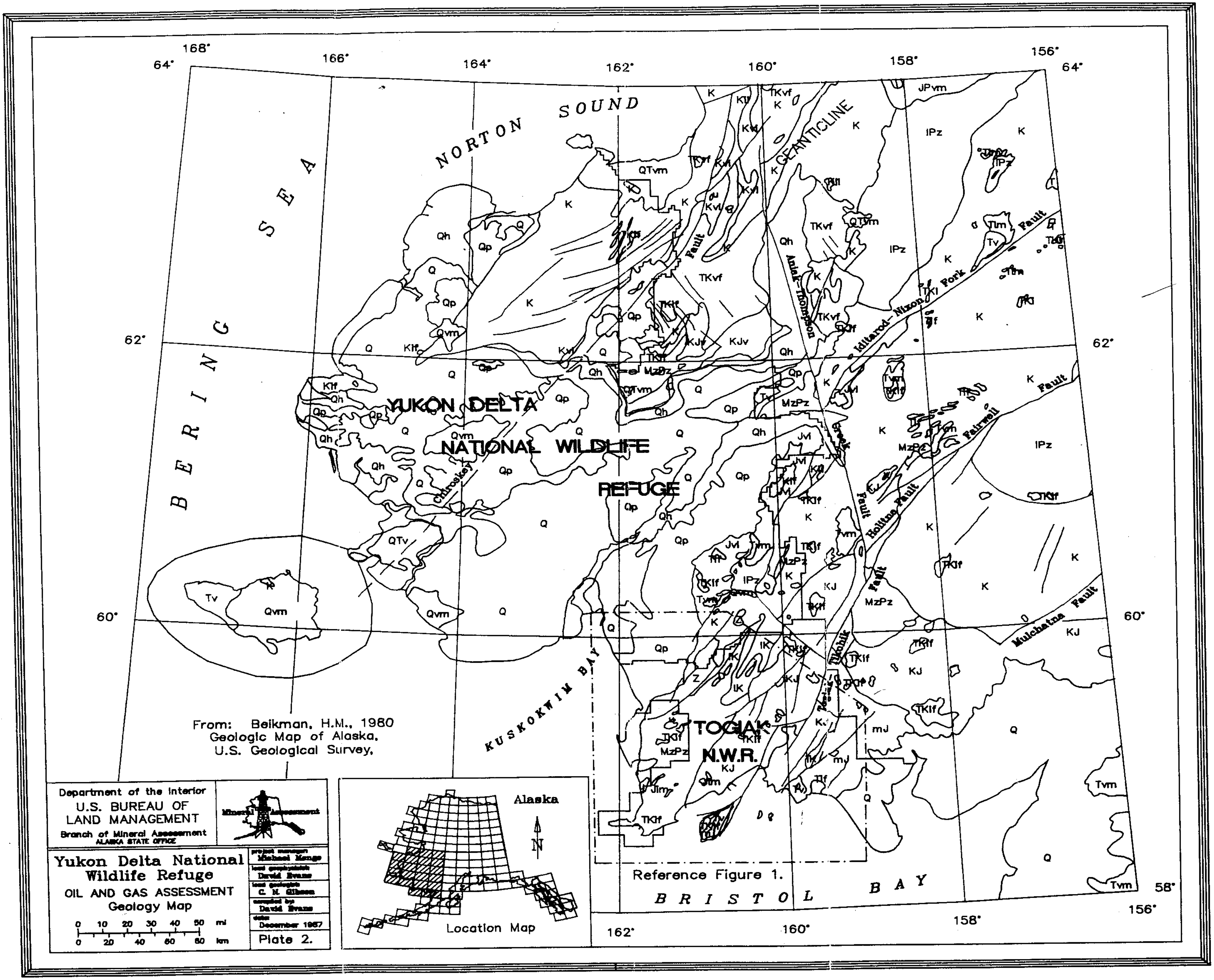
Branch of Mineral Assessment
ALASKA STATE OFFICE

Yukon Delta National Wildlife Refuge
OIL AND GAS ASSESSMENT
Land Status Map

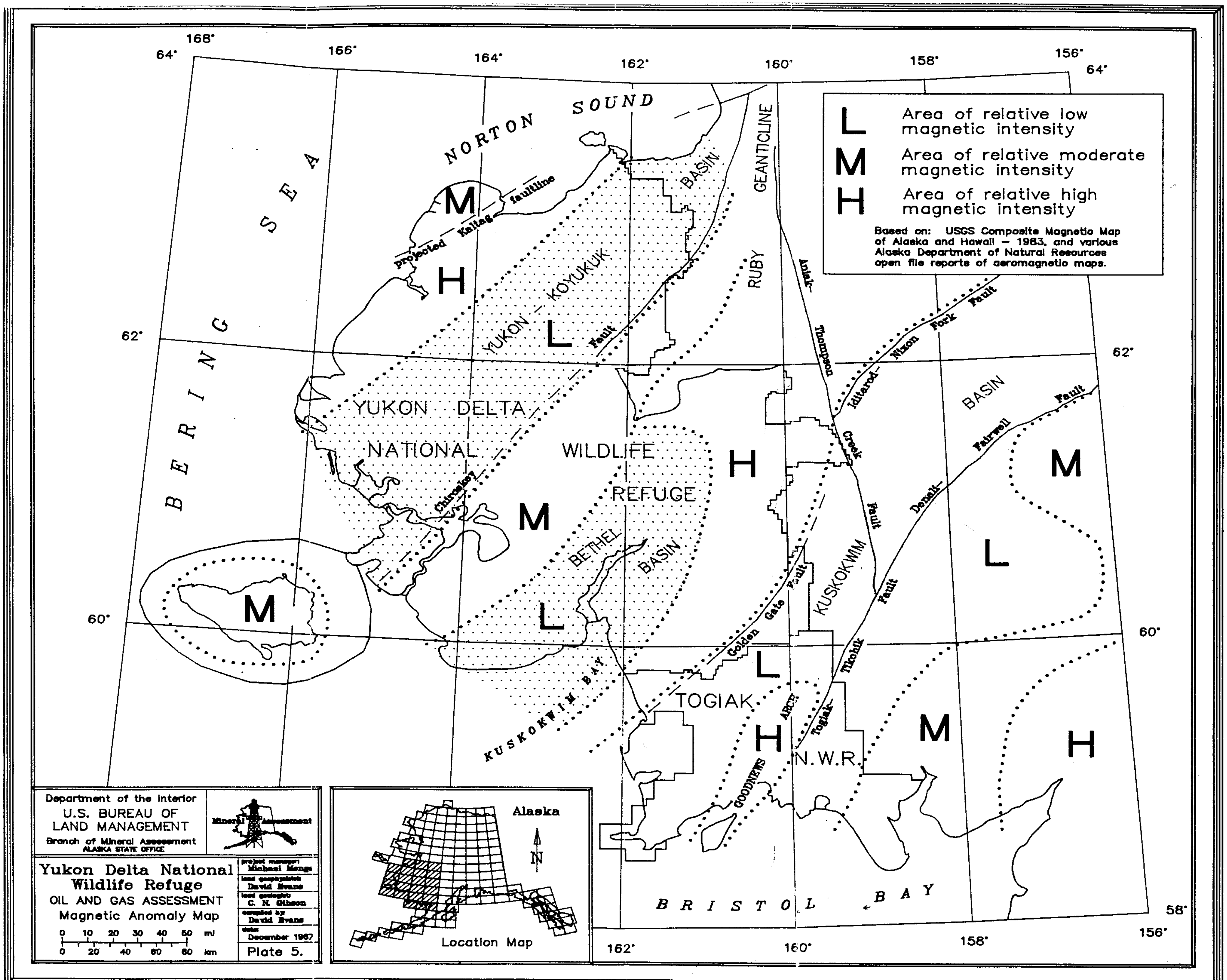
0 10 20 30 40 60 mi
0 20 40 60 80 km

project manager Michael Kunge
lead geophysicist David Evans
lead geologist C. N. Gibson
compiled by David Evans
date December 1987

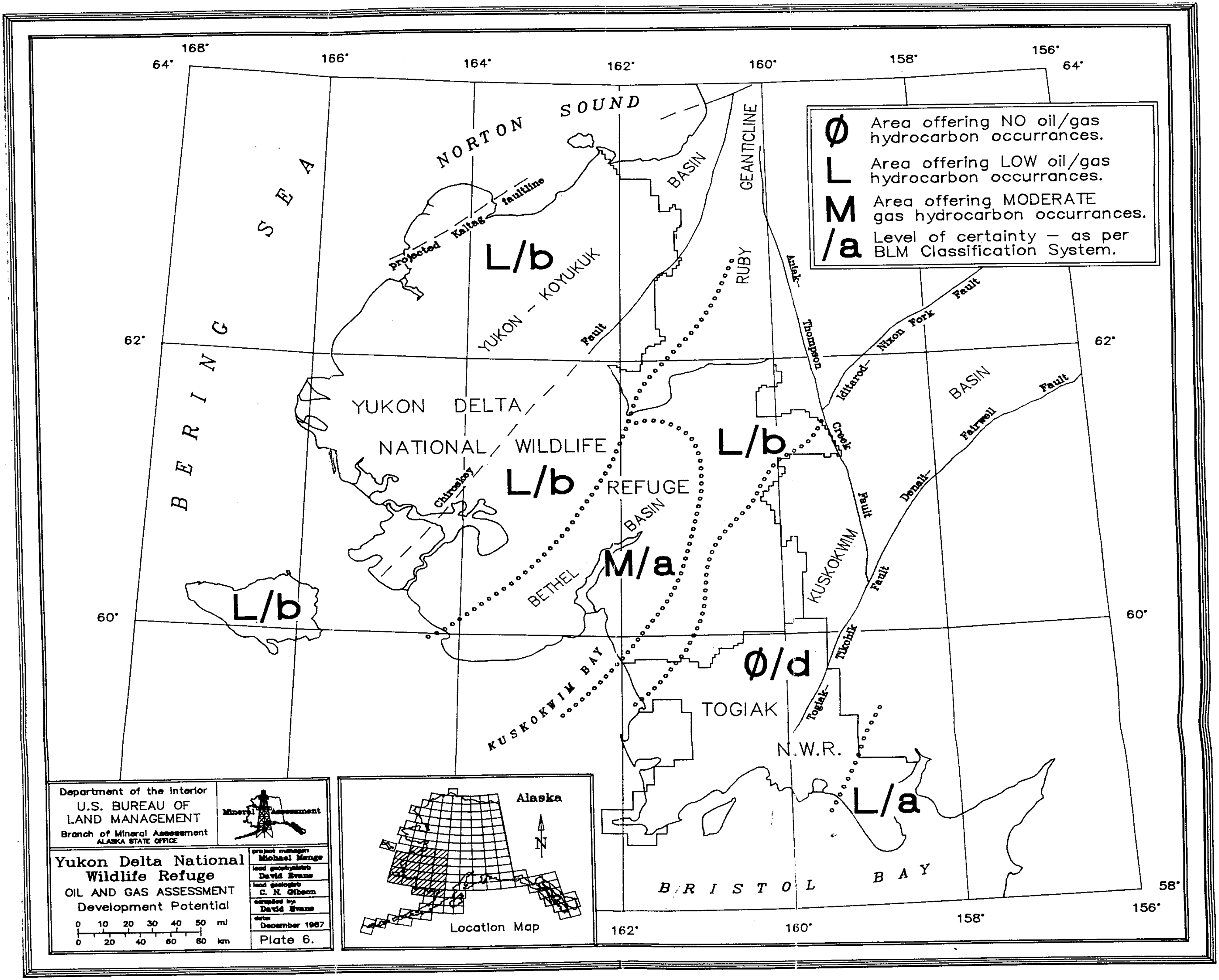
Plate 1.



NORTON SOUND
BERING SEA
KUSKOKWIM BAY
BRISTOL BAY
YUKON DELTA NATIONAL WILDLIFE REFUGE
TOGIAK N.W.R.
GEANTICLINE
Aniak-Thompson Creek Fault
Iditarod-Nixon Fork Fault
Farewell Fault
Holitna Fault
Mulchatna Fault
Tikchik
Chiroskey
Reference Figure 1.
From: Beikman, H.M., 1980
Geologic Map of Alaska,
U.S. Geological Survey,
Alaska
N
Location Map
Department of the Interior
U.S. BUREAU OF
LAND MANAGEMENT
Branch of Mineral Assessment
ALASKA STATE OFFICE
Mineral Assessment
Yukon Delta National
Wildlife Refuge
OIL AND GAS ASSESSMENT
Geology Map
project manager Michael Menge
lead geophysicist David Evans
lead geologist C. N. Gibson
compiled by David Evans
date December 1987
Plate 2.
0 10 20 30 40 50 mi
0 20 40 60 80 km



L Area of relative low magnetic intensity
M Area of relative moderate magnetic intensity
H Area of relative high magnetic intensity
Based on: USGS Composite Magnetic Map of Alaska and Hawaii – 1983, and various Alaska Department of Natural Resources open file reports of aeromagnetic maps.
NORTON SOUND
BERING SEA
BRISTOL BAY
KUSKOKWIM BAY
YUKON DELTA NATIONAL WILDLIFE REFUGE
YUKON – KOYUKUK BASIN
BETHEL BASIN
RUBY GEANTICLINE
KUSKOKWIM
TOGIAK N.W.R.
TOGIAK ARCH
GOODNEWS ARCH
projected Kaltag faultline
Chiroskey
Fault
Aniak–Thompson Creek Fault
Iditarod–Nixon Fork Fault
Denali–Fairwell Fault
Golden Gate Fault
Togiak–Tikchik Fault
BASIN
168° 166° 164° 162° 160° 158° 156°
64° 62° 60° 58°
Alaska
N
Location Map
Department of the Interior
U.S. BUREAU OF LAND MANAGEMENT
Branch of Mineral Assessment
ALASKA STATE OFFICE
Mineral Assessment
Yukon Delta National Wildlife Refuge
OIL AND GAS ASSESSMENT
Magnetic Anomaly Map
0 10 20 30 40 50 mi
0 20 40 60 80 km
project manager Michael Menge
lead geophysicist David Evans
lead geologist C. N. Gibson
compiled by David Evans
date December 1987
Plate 5.



Ø Area offering NO oil/gas hydrocarbon occurrances.
L Area offering LOW oil/gas hydrocarbon occurrances.
M Area offering MODERATE gas hydrocarbon occurrances.
/a Level of certainty — as per BLM Classification System.
NORTON SOUND
BERING SEA
BRISTOL BAY
KUSKOKWIM BAY
YUKON DELTA NATIONAL WILDLIFE REFUGE
TOGIAK N.W.R.
YUKON - KOYUKUK BASIN
BETHEL BASIN
KUSKOKWIM BASIN
RUBY GEANTICLINE
Projected Kaltag faultline
Fault
Chiroskey
Aniak-Thompson Creek Fault
Iditarod-Nixon Fork Fault
Denali-Farewell Fault
Tikchik-Togiak
L/b
L/b
L/b
L/b
M/a
Ø/d
L/a
64°
62°
60°
58°
168°
166°
164°
162°
160°
158°
156°
Alaska
N
Location Map
Department of the Interior
U.S. BUREAU OF LAND MANAGEMENT
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ALASKA STATE OFFICE
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Yukon Delta National Wildlife Refuge
OIL AND GAS ASSESSMENT
Development Potential
project manager: Michael Menge
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Plate 6.
0 10 20 30 40 50 mi
0 20 40 60 80 km